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Strengthening Community College Engineering Programs through Alternative Learning Strategies: Developing Resources for Flexible Delivery of a Materials Science Course

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Strengthening Community College Engineering Programs through Alternative Learning Strategies: Developing Resources for Flexible Delivery of a Materials Science Course

Abstract:

Community colleges provide an important pathway for many prospective engineering graduates, especially those from traditionally underrepresented groups. However, due to a lack of facilities, resources, student demand and/or local faculty expertise, the breadth and frequency of engineering course offerings is severely restricted at many community colleges. This in turn presents challenges for students trying to maximize their transfer eligibility and preparedness. Through a grant from the National Science Foundation Improving Undergraduate STEM Education program (NSF IUSE), three community colleges from Northern California collaborated to increase the availability and accessibility of a comprehensive lower-division engineering curriculum, even at small-to-medium sized community colleges. This was accomplished by developing resources and teaching strategies that could be employed in a variety of delivery formats (e.g., fully online, online/hybrid, flipped face-to-face, etc.), providing flexibility for local community colleges to leverage according to their individual needs. This paper focuses on the iterative development, testing, and refining of the resources for an introductory Materials Science course with 3-unit lecture and 1-unit laboratory components. This course is required as part of recently adopted statewide model associate degree curricula for transfer into Civil, Mechanical, Aerospace, and Manufacturing engineering bachelor's degree programs at California State Universities. However, offering such a course is particularly challenging for many community colleges, because of a lack of adequate expertise and/or laboratory facilities and equipment. Consequently, course resources were developed to help mitigate these challenges by streamlining preparation for instructors new to teaching the course, as well as minimizing the face-to-face use of traditional materials testing equipment in the laboratory portion of the course. These same resources can be used to support online hybrid and other alternative (e.g., emporium) delivery approaches. After initial pilot implementation of the course during the Spring 2015 semester by the curriculum designer in a flipped student-centered format, these same resources were then implemented by an instructor who had never previously taught the course, at a different community college that did not have its own materials laboratory facilities. A single site visit was arranged with a nearby community college to afford students an opportunity to complete certain lab activities using traditional materials testing equipment. Lessons learned during this attempt were used to inform curriculum revisions, which were evaluated in a repeat offering the following year. In all implementations of the course, student surveys and interviews were used to determine students' perceptions of the effectiveness of the course resources, student use of these resources, and overall satisfaction with the course. Additionally, student performance on objective assessments was compared with that of traditional lecture delivery of the course by the curriculum designer in prior years. During initial implementations of the course, results from these surveys and assessments revealed low levels of student satisfaction with certain aspects of the flipped approach and course resources, as well as reduced learning among students at the alternate institution. Subsequent modifications to the curriculum and delivery approach were successful in addressing most of these deficiencies.

1. Introduction

Community colleges have been acclaimed as an essential component in our nation's STEM education system, and as perhaps the most important component in terms of producing a more diverse STEM workforce.[1,2] The California Community College (CCC) system, with its 113 colleges enrolling over 2 million students, will be a major contributor to this effort.[3] However, at present many CCC engineering students lack sufficient access to some of the lower-division (LD) engineering courses needed for successful transfer acceptance into public university programs in the state.[4] More than half of the 113 CCCs offer few if any of the LD engineering courses, and among those that do sustain a reasonably comprehensive LD engineering curriculum, most offer only one section of each engineering course per year.

In an effort to increase access to LD engineering courses by CCC students, the Joint Engineering Program (JEP) was created, developed initially through a grant from the National Science Foundation and later supported by a grant from the US Department of Education. JEP, which has grown to include 27 community college across California, promotes partnership by aligning curriculum, sharing teaching resources and best practices, and helping students to access required engineering courses, often via online offerings at partner institutions. Leveraging these efforts, three of the JEP colleges, Cañada College, College of Marin, and Monterey Peninsula College collaborated to develop and obtain NSF support for Creating Alternative Learning Strategies for Transfer Engineering Programs (CALSTEP). The goal of this program is the development and continuous improvement of a range of alternative delivery models that aim to build capacity among community colleges and to develop inquiry-based curriculum that can be used in both online and flipped courses, especially those with laboratory components. The courses developed include Introduction to Engineering, Engineering Graphics, Materials Science, Circuits, and MATLAB Programming.

The focus of this paper, however, is the development of the resources for the Materials Science course, its pilot implementation as a flipped course at College of Marin in Spring 2015, and its subsequent implementations in Fall 2015 and in Fall 2016 by an instructor who had never previously taught the course, at Monterey Peninsula College, a community college that lacked materials lab facilities. The flexible nature of the course resources allowed the instructor with minimal advance notice or preparation to deliver the course to students, conducting most of the lab activities on site and arranging a single visit to a neighboring college so that students could gain exposure to the use of materials testing equipment while completing one of the labs in the course. Student surveys and interviews, as well as objective assessments of learning, were used to inform and evaluate modifications to the curriculum between iterations.

2. Development and Pilot Implementation of Curriculum

A more detailed description of the development and pilot implementation of the curriculum are provided in a previous paper.[5] A summary of salient information is provided here.

Development of Curriculum

The curriculum and resources for the materials science course in this study were designed so as to:

A. Align with a statewide course descriptor[6] for a 4-unit (3-unit lecture and 1-unit lab) introductory materials science course, which is required as part of a statewide 2-year transfer model curriculum for students in Aerospace, Civil, Mechanical, and Manufacturing Engineering.[7]

B. Allow flexibility for a variety of delivery formats (e.g., flipped, online, emporium, etc.).

C. Achieve the thirteen objectives for engineering educational laboratories defined by the ABET/Sloan Foundation effort.[8]

D. Require some minimum number of on-campus experiments in a traditional materials testing lab that would satisfy objectives A and C above, yet provide a manageable solution for online students or for institutions lacking traditional materials testing equipment.

The course curriculum was developed by a community college instructor with a background in chemical engineering, who had taught the materials science course for the previous 14 years in a traditional lecture format. An advisory board was assembled to provide guidance during development of the curriculum. This advisory board had representatives from all segments of California public higher education, including faculty with ample experience teaching introductory materials science courses.

The initial curriculum and pilot implementation were designed around a flipped approach, which has been demonstrated as more effective for learning in many science and engineering contexts.[9,10,11,12,13] Such student-centered approaches also naturally support greater flexibility in course delivery. For example, many of the same resources developed for quality online instruction, such as recorded video content, computer-based tutorials, real-time assessment and feedback, student-led inquiry and discussions, individual and team problem-solving activities, etc., can be used to support flipped-classroom instruction. Another advantage of such student-centered approaches is the more individualized character to the learning environment, enabling instructors to more easily accommodate a group of students with diverse preparation and ability.

For the initial pilot implementation of the materials course, students were expected to read from a textbook and view video lessons outside of class, and then use class time for group problem-solving sessions and laboratory experiments. In order to investigate student preferences regarding video formats, the initial set of video lessons consisted of both original content by the curriculum designer, as well as existing content produced by other instructors in a variety of formats (voice-over slides, brief screencast video modules, full-length lecture archives, etc.). For in-class activities, in addition to the lab curriculum, problem sets were developed to explore content in a team setting, and multiple-choice questions were written to provide brief formative assessment of individual learning of key concepts in each lesson.

Although the pilot implementation required students to complete all labs in person, many of the labs were designed for possible at-home completion in a future online or hybrid delivery of the course or at an institution lacking materials testing equipment. These labs primarily used physical and virtual modelling approaches, as well as qualitative testing of materials, in order to reinforce and further explore content addressed in the reading, lecture videos and problem sets. Some of these labs also asked students to analyze authentic experimental data that was supplied by the instructor. By introducing relevant data analysis tools and techniques, as well as concepts of uncertainty analysis and limitations in the applicability of theoretical models, some of these earlier labs laid important groundwork for the hands-on testing labs later in the course, which typically provided less guidance and demanded greater independence on the part of students. The most important of these was a 3-part brass lab series (Strain Hardening, Annealing, Process Design Challenge), which addressed all 13 engineering lab learning objectives to some degree. In fact, several members of the advisory board had indicated that this one lab series would be adequate as the only face-to-face lab requirement in a possible online/hybrid delivery of the course. This approach would maximize flexibility, since in theory it could be completed in one or two full-day sessions.

A complete description of the curriculum, including course objectives, topics covered, and descriptions of the lab experiments and learning objectives, can be found at http://www.canadacollege.edu/nsf-iuse/.

Pilot Implementation

The curriculum was first implemented during the Spring 2015 semester at the designer's home institution College of Marin (COM), located near San Francisco, CA. As a member of the CCC system, COM is an open-enrollment institution. During the 2014-2015 academic year, the college enrolled 9,317 students, of whom 46% are white and 30% are Hispanic. Approximately 10 to 20 COM students transfer each year into four-year Engineering programs in CA public universities, enabled by COM's effort to offer a comprehensive set of common LD engineering courses. The Spring 2015 Materials Science class consisted of 16 students, of whom 75% were white and 87% were male.

As described above, students were assigned to read textbook pages and to watch pre-recorded lecture modules outside of class time, and to complete individual quizzes, group problem-solving exercises, and laboratory activities during the two 3-hour class sessions each week. Two midterm exams and a comprehensive final exam were used to evaluate achievement of student learning objectives for the course. The same course final exam had been administered the previous four years (Spring 2011 through Spring 2014), allowing comparison of student learning in the flipped course with that in the prior traditional lecture format. In order to evaluate the learning gains made by students in the course, and to serve as a baseline for comparisons across institutions, two different assessments were administered at the beginning (Pre) and at the end (Post) of the course. One of these assessments was the Materials Concept Inventory (MCI), a 30-question multiple-choice assessment instrument developed by faculty at Arizona State University and Texas A&M University to measure conceptual understanding of topics in introductory materials science courses.[14] Although recent analysis has pointed out significant limitations in using this instrument to assess learning, it is the only broadly available tool to measure learning gains in introductory materials science courses.[15,16] The second assessment, developed in house, consisted of a small subset of traditional final exam questions in the course that were more applied in nature and not fully addressed by the MCI. These questions included materials classification and property ranking exercises, as well as crystallography, stress-strain, and phase diagram analysis problems.

Student preferences regarding video lesson formats were evaluated using a video survey for each lesson. The survey asked students to report the length of time spent watching each lesson, to rate their ability to maintain focus and their level of understanding of the content, and to report on what they liked best and least about each lesson.

Overall attitudes about the course experience and resources were evaluated using written surveys by all students, as well as follow-up 20-minute interviews conducted by the project researcher with the instructor and a representative subset of students. A similar version of the written survey was also administered to students in the subsequent implementations of the course at Monterey Peninsula College, and is provided in Appendix A.

Results of Pilot Implementation

As indicated in Table 1, there were no significant differences in success rates or final exam scores between the students in the flipped class and those in the prior lecture classes, even though the flipped class had approximately double the enrollment of the prior classes. Students in the flipped class demonstrated substantial gains in learning as measured by the more applied in-house (Analysis) pre/post assessment, increasing from an average 52% correct on the pre-test to an average 90% correct on the post-test, or an average normalized gain[17] $g_{\%}$ = 79% of the possible learning gain on this assessment instrument. For the more conceptual MCI assessment, the gain $g_{\%}$ = 32% was more modest; however, this value compared favorably with gains of 10% to 30% on the MCI that have been reported by others for similar courses.[14,16,18]

The video surveys revealed substantial variation among students in both compliance and preferences. In terms of viewing times, 15% to 40% of respondents (depending upon the lesson) reported zero minutes of viewing, while similar percentages reported not only watching the entire lesson, but also repeatedly watching certain portions. Notably, when the lesson was recorded by the course instructor, 63% of students on average reported watching the entire lesson, as compared to only 33% for lessons recorded by another presenter. In addition to this bias in favor of the course instructor, a majority of students also expressed preferences for modular lessons composed of 4 to 6 brief, studio-recorded videos that were streamed in a player with high-speed playback options (e.g., YouTube). Students expressed low levels of satisfaction with full-length (60 to 120 minute) lectures, especially if these were recorded archives of prior classroom presentations that included interaction with students. Students on average also rated voice-over slide presentations as less effective for their learning; however, some students praised the efficiency of navigation afforded by this medium.

In the course survey and interviews, students expressed universally high levels of satisfaction with in-class activities such as labs, problem sets, and group learning in general, but had mixed responses to the overall flipped approach of the course (see Table 2). Although some students commented that they found the labs challenging and time consuming, most students listed the lab among the things that they liked best about the course and that they felt contributed the most to

Table 1. Comparison of student performances for traditional lecture courses at COM 2011-2014, and for flipped courses at COM Spring 2015, at MPC Fall 2015 and at MPC Fall 2016.

	COM Lecture 2011-2014		COM Flipped Spring 2015		MPC Flipped Fall 2015		MPC Flipped Fall 2016	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Students Enrolled	7.8	1.0	16		19		14	
Students Retained	7.0	1.4	13		16		11	
Students Passed	6.5	1.7	12		15		11	
Success Rate	83%	14%	75%		79%		79%	
Final Exam	82%	11%	86%	10%	*74%	10%	*77%	11%
Analysis Pre			52%	10%	56%	10%	*44%	8%
Analysis Post			90%	7%	*69%	9%	81%	14%
**Analysis Gain $g_{\%}$			79%	12%	*27%	25%	64%	26%
MCI Pre			44%	12%	42%	14%	*30%	9%
MCI Post			61%	12%	*46%	11%	*45%	11%
**MCI Gain $g_{\%}$			32%	14%	*5%	15%	21%	10%

*Scores were significantly different from those for COM Spring 2015 ($p<0.05$).

**Gain $g_{\%}$ = (Post – Pre) / (100% – Pre)

their learning. When rating how much various course activities contributed to their learning on a 5-point scale (1 = Least, 5 = Most), students on average rated labs (4.1) and lab analysis (3.9) higher than any other activities, with the exception of in-class mini-lectures by the course instructor (4.4). Watching videos received low ratings (2.8) and was the source of most negative survey and interview comments, with nearly half of comments indicating a desire for more in-class lectures (rather than at-home viewing of videos). In general, activities that students performed outside of class (the first 5 activities listed in Table 2) received lower ratings than activities performed in class, with the exception of the in-class quizzes, which students rated the lowest (1.9) in terms of contribution to their learning. Nevertheless, students acknowledged the importance of quizzes as motivational tools, indicating 43% *yes*, 36% *not sure*, and only 21% *no*, when asked whether the quizzes motivated them to watch videos and/or read the text in preparation for class.

Modifications to the Course Resources

In response to student feedback, some modifications were made to the course resources in order to improve their utility for student learning. In particular, most of the voice-over slide presentations and longer video lectures were replaced with brief modular YouTube videos. Some of these brief videos were recorded by the course developer, while others were selected from publicly available YouTube videos produced by materials science faculty at various universities

Table 2. Comparison of student responses to selected end-of-course survey questions from COM Spring 2015, MPC Fall 2015 and MPC Fall 2016.

		COM S15	MPC F15	MPC F16
Overall impression				
Would HIGHLY recommend course		38%	0%	18%
Would NOT recommend course		23%	71%	18%
Course structure and student effort				
Weekly class sessions (hrs)		3+3	4.5	1.5+1.5+3
Estimated time spent on course? (hrs/week)		16.4	7.3	10.4
Watched >75% of each video lesson?		55%	64%	100%
Quizzes motivate preparation?	Yes	43%	73%	45%
	No	21%	9%	9%
Contribution of activities to learning? (1 = Least, 5 = Most)				
Watching videos		2.8	3.7	4.1
Reading textbook		3.1	3.0	2.2
Finding info online		2.3	3.1	3.2
Working problems outside class		3.0	3.1	4.0
Preparing for lab		3.1	2.2	2.8
In-class quizzes		1.9	3.2	2.9
Working problems in class		3.7	2.7	4.4
In-class mini-lecture		4.4	3.0	2.7
Doing hands-on labs		4.1	3.1	4.3
Lab data analysis		3.9	2.1	3.3
Test Prep study guides*		N/A	3.2	4.2
Field lab at Cañada College*		N/A	4.4	4.3
Lab (1 = Strongly Disagree, 5 = Strongly Agree)				
Strong lecture-lab connection		4.5	2.9	3.7
Labs reinforced lecture concepts		4.4	2.7	3.5
Labs taught additional skills		4.6	3.0	2.9
Understood learning objectives before lab		3.8	2.4	2.6
Understood learning objectives after lab		4.4	2.8	3.4
Sufficient guidance on labs		3.9	2.0	2.6
Liked about group learning? (1 = Liked least, 5 = Liked most)				
Working as part of a team		4.0	3.7	4.6
Solving problems together		4.5	3.9	4.5
Working with people who think differently		3.5	3.3	4.2
Explaining concepts to less prepared students		4.1	3.8	4.2
Learning from mistakes		4.0	3.4	4.1

*These questions did not appear in the survey of COM students.

(e.g., Texas A&M, Arizona State, UC Boulder, U Toronto, etc.). In addition, a set of slides was developed for each lesson in the course, in order to provide students with an easy-to-navigate guide to key learning concepts and objectives.

3. First Implementation at Alternate Institution

Monterey Peninsula College (MPC) is a member of the CCC system and is located on the central coast of CA. During the 2014-2015 academic year, the college enrolled 14,578 students, of whom 47% were white and 31% were Hispanic. The Fall 2015 Materials Science class consisted of 19 students, of whom 50% were white and 77% were male. As with COM, MPC has a small Engineering transfer program that offers a comprehensive set of lower-division engineering courses needed for transfer. However, the Materials Science course had been recently added to the curriculum, and due to lack of materials testing equipment at the college, required special arrangements for use of facilities at another institution.

The adjunct instructor originally assigned to teach the Materials course withdrew during the first week of the semester due to personal reasons. Because most of the 19 enrolled students needed the course to successfully transfer in a timely manner, the full-time Engineering instructor at MPC stepped in to teach the course. This decision was contingent on availability of the CALSTEP materials course resources, since the instructor already had a full teaching load, had never taught the course previously, and had a professional background in electrical engineering and computer science that had provided him only limited exposure to materials science concepts. The project grant support also enabled the instructor to hire a teaching assistant for the course who had previously been an MPC student and had recently graduated with an engineering degree from UCLA.

The MPC course was taught using the curriculum developed at COM, along with supplements created by the MPC instructor. Because of scheduling availability, however, students only met once per week for a single 4.5-hour session in an online/hybrid format. Students were expected to complete both the lecture viewing and the problem sets outside of class, and to use class time primarily for completing the labs, with some time available for assistance with the problem sets. Because MPC did not have materials lab facilities, the instructor arranged to visit another CALSTEP community college (Cañada College) to use their facilities (including tensile testers, hardness testers, and furnaces) for completing the final component of the 3-part Brass Lab experiment. This required students to apply results from the first two experiments (strain hardening and annealing) in order to design, execute, and evaluate a process for achieving property objectives specified by the instructor. The other 11 lab assignments in the course were completed at MPC, and emphasized qualitative, modeling, and virtual approaches for concept exploration, combined with analysis of data from actual materials testing experiments that had been collected by previous COM students. As a result, MPC students conducted 8 of the 12 lab activities in the same manner as had the COM students, but used a virtual/analysis approach in 4 of the labs that had involved hands-on testing by COM students.

Students in the Fall 2015 MPC course were given the same pre and post MCI and Analysis assessments, as well as the same course final exam, that had been administered to the Spring 2015 COM students. Similarly, the project researcher administered written surveys to all students (see Appendix A), and conducted follow-up interviews with the instructor, the teaching assistant, and a representative subset of students.

Results of First Implementation at Alternate Institution

Of the 19 students who enrolled in the course, 16 persisted to the end of the semester, and 15 received passing grades (i.e., a success rate of 79%). Of these, 13 students completed both Pre and Post assessments. Table 1 compares the performance of Fall 2015 MPC students with that of Spring 2015 COM students. Class sizes and demographics appeared fairly comparable between the two groups, and there were no significant differences in Pre scores on either the MCI or Analysis assessments. Post scores on these assessments and on the course final exam were significantly higher among the COM group. Fall 2015 MPC students demonstrated significant learning gains on the in-house analysis problems, and acceptable mastery of the material on the course final exam (74% average), but showed no significant average gain in the types of conceptual understanding measured by the MCI. One possible explanation for this latter result may be the use of test preparation study guides, which were created by the MPC instructor. Although this approach likely achieved its goal of improving students' focus on some of the applied knowledge and skills included on the course exams and Analysis assessment, it may not have contributed as much to their broad understanding of fundamental concepts (and robust misconceptions) assessed by the MCI.

Student responses to selected questions from the course survey and interviews are summarized in Table 2. MPC students expressed lower levels of satisfaction than COM students with most aspects of the course. When COM students had been asked whether they would recommend to a friend taking the class in its present flipped format, 23% *would not*, while 38% were definitive and the rest more tentative in their recommendations. The comparative results among MPC students were that 71% *would not,* with the rest providing only tentative recommendations (none would highly recommend). Some key challenges reported in both surveys and interviews by MPC students included difficulty in understanding how to complete the labs, insufficient familiarity with how to use spreadsheet software (e.g., Excel) to analyze data, and the large time commitment required to be successful in the course. Overall, most students reported that they struggled to learn the material and complete the course assignments. By contrast, a smaller group of MPC students expressed a higher level of satisfaction with the overall course experience during their interview responses. These students appeared to be more self-motivated and persistent in their determination to master the material, describing their efforts to consult multiple sources when encountering problems, as well as the satisfaction they derived from learning. These students reported that they had learned a tremendous amount from this class and had completed the course feeling that while the experience had been time-consuming and difficult, it was also worthwhile.

Interviews with the instructor and teaching assistant revealed that they found the course difficult to teach, struggled with some of the lab assignments, and spent more time preparing for the class than they had expected. The instructional team also noted that many students arrived to class without adequate preparation, often not having read the lab handout, and therefore feeling lost given the student-centered nature of the curriculum. This latter observation was corroborated by MPC students' estimates of the total time spent on the course (including class time and preparation), which averaged 7.3 hours per week (range from 5 to 10), far below the typical expectations of a 4-unit engineering course, and seemingly at odds with student comments about the large workload for the course. The employment status of students in the class might provide a partial explanation for why many were unable to dedicate more time to the course even though they were struggling. Among the survey respondents, 73% were employed 12 or more hours per week, and 40% were employed 20 or more hours per week. However, students who were employed 5 or fewer hours per week did not report spending more time on the course than other students. Moreover, when students were asked how many hours they would need to spend on the course in order to do as well as possible, the median estimate rose to only 10 hours, less than the nominal 12-hour workload expected for a 4-unit course. Given that most community college students are underprepared for the courses in which they enroll, this discrepancy in workload expectations was likely an important contributing factor to their dissatisfaction with the course, as well as to their lower performance on the course assessments as compared to COM students.

On a more positive note, MPC students reported higher satisfaction than had COM students with the online video lessons. The average 5-point rating given by students for the videos' contribution to their learning rose from 2.8 among COM students to 3.7 among MPC students, and the proportion of students who reported watching on average more than 75% of each video lesson rose from 55% of COM students to 64% of MPC students. Although replacing the longer video lectures with brief modular YouTube videos did appear to improve students' ability to use the videos as a learning resource, nevertheless some students commented that having videos from different presenters and institutions made it harder for them to understand the material. Many students commented that the videos recorded by the COM professor and by Professor Shamberger of Texas A&M University seemed to most closely align with the learning objectives needed for the problem sets, labs, and exams.

Additionally, although students reported difficulty in completing most of the labs conducted at MPC, they acclaimed the "field trip" to Cañada College to complete the brass lab as the highlight of the course. This field lab earned the highest average rating (4.4) by far among all course activities in perceived importance to their learning, with 90% of students awarding it the maximum rating (5). In interviews, students emphasized how rewarding it was to apply the theoretical concepts from the course to the processing and testing in a real materials lab.

Further Modifications to the Course Resources

In response to the feedback from MPC students and instructor, further modifications were made to both the lab and lecture resources. In particular, efforts were made to reduce the complexity and quantity of spreadsheet data analysis needed for many of the labs, to increase the amount of hands-on testing of authentic engineering materials, and to provide somewhat more guidance to both students and instructors regarding lab procedures and expected results, including a complete set of "instructor resources" for all of the problem sets and labs. As one important example, an ionic bond modeling lab that required a rather involved spreadsheet analysis of bond force and energy curves was removed from the curriculum. In its place, a new lab was developed that provided students with a "big picture" exploration of materials science and engineering at the start of the course. In this lab, students used cantilever bend testing of rods (adaptable to at-home execution) to explore how material properties are defined, measured, and applied during selection of materials for an engineering design (e.g., a bottle opener). In addition, students evaluated the mechanical behavior of bobby pins and copper wires that had been subjected to cold-working, annealing, and quenching treatments, in order to observe how processing can modify properties. In essence, this new lab was intended to spark the type of curiosity and excitement that had been elicited by the brass lab experience at Cañada College.

In order to address students' expressed desires for greater consistency of video presenters, newly recorded videos by the COM instructor or existing ones by Shamberger were used to replace many of the other videos, resulting in more than 80% of the roughly 150 videos in the course being from these two presenters. Additionally, some of the longer lessons were broken down into two shorter lessons, resulting in all lessons having total durations of 45 to 60 minutes (or 30 to 40 minutes at the students' anecdotally preferred playback speed of 1.5x). In order to more closely guide student learning, the problem sets were rewritten with the intention to be completed while watching the lessons, explicitly correlating each video in the lesson with several problems intended to emphasize the key learning objectives of that video.

4. Second Implementation at Alternate Institution

The revised version of the curriculum was once again implemented at MPC the following year. This Fall 2016 class consisted of 14 students, of whom 64% were white and 86% were male. Students were offered two different choices in terms of attending class—an online/hybrid (OL) section with one mandatory 3-hour lab session each week (7 students), or a face-to-face (F2F) section with two additional 1.5-hr weekly lecture classes (7 students). Gender and ethnic composition of the two groups was similar. Both groups of students were expected to complete the problem sets while watching the video lessons, but the students in the F2F section were expected to attend the lecture classes to discuss the problems (and potentially lab analysis) with their classmates and instructor. In practice, some of the students in the OL section attended the lecture classes occasionally or even frequently for support, while some of the students in the F2F section failed to attend regularly, resulting in a continuous gradient of contact hours rather than two distinct groups. In addition to the full-time MPC instructor, the college hired an adjunct co-instructor with a background in materials science but minimal prior teaching experience. Officially, the full-time instructor was assigned to the lab portion and the adjunct to the lecture portion, but in reality there was considerable overlap in responsibility and effort. As in the prior year, the instructor arranged a single site visit to Cañada College in order to use their facilities for completing the Brass Lab experiment.

Results of Second Implementation at Alternate Institution

As indicated in Table 1, 11 students persisted to the end of the course and completed the final exam, post-course assessments, and survey. Among these students, average pre-course scores on both the Analysis and MCI assessments were significantly lower as compared to both COM and MPC students in 2015. Final exam scores were also significantly lower as compared to COM Spring 2015 students, but slightly higher on average than scores for MPC Fall 2015 students. More importantly, the gains on the Analysis and MCI assessments were not significantly different from COM Spring 2015 students, but were significantly higher as compared to MPC

Fall 2015 students. MPC Fall 2016 students demonstrated significant and uniformly positive gains on both assessments, indicating improved learning relative to the Fall 2015 class.

Based on survey responses, attitudes regarding the course also improved from the previous class. Only 18% of students indicated that they would not recommend the flipped course to a friend. Total time spent working on the course rose to a more reasonable average of 10.4 hours per week, despite average weekly employment that was also higher than the Fall 2015 cohort. And 100% of students indicated that they watched on average more than 75% of each video lesson. As evidenced by average ratings of importance to learning, student impressions of virtually all course activities improved relative to Fall 2015. In particular, watching videos, working problems (inside and outside class), and doing labs received average ratings above 4, suggesting that the modifications to these resources had proven successful.

Student perceptions about the lab component of the course had improved relative to MPC Fall 2015 students, with higher average ratings of agreement for nearly all lab survey questions. Nevertheless, these average ratings remained substantially lower than those of COM students, and were at or below 3 (neutral) on whether students understood the learning objectives before lab, had sufficient guidance on how to complete the labs, and learned additional skills beyond the lecture course. Since the learning objectives for each lab were described in detail on the first page of each lab handout, it seems likely that inadequate student preparation or attention (an observation that was also made by the MPC instructional team) provides a partial explanation for these results. Given the less prescriptive and more inquiry-oriented nature of many labs in this curriculum, poor preparation may have contributed to students' reported lack of sufficient guidance on how to perform the labs. The apparent correlation between the class average lab ratings and the class average time spent on the course (hrs per week) lends further support to this explanation.

Another contributing factor, however, especially to lesser agreement by MPC students that the lab teaches additional skills, is that several of the hands-on lab experiments conducted by COM students had been replaced with virtual/data analysis versions for MPC students. Although MPC students clearly placed high value on the lab testing conducted at Cañada College, this single experience with traditional materials testing equipment may have been insufficient to convince them of the "authenticity" of their lab experience in the course, or perhaps during survey completion, they compartmentalized this experience as separate from the rest of the lab activities when making their evaluations. Moreover, the approach used in the virtual analysis labs may have proved inadequate in contextualizing the data, thereby diminishing students' ability to guide their own analytical efforts as well as to gain confidence in their mastery of the related laboratory analysis skills. In order to address these deficiencies in the future, modifications to the analysis labs might include additional supporting media resources (e.g., photographic slides, demonstration videos, etc.) as well as brief hands-on activities that provide at least qualitative manifestations of the phenomena under analysis.

5. Conclusions and Future Plans

The Materials curriculum proved successful during its pilot implementation as a flipped course at College of Marin. By all objective measures, students performed at least as well as those who had taken the course in prior years when it was delivered in a traditional lecture format, demonstrating substantial learning gains according to multiple measures. Moreover, students reported high levels of satisfaction with the laboratory component of the course. They felt that it not only reinforced the lecture content, but also conferred additional knowledge and skills beyond what was covered in the text, lecture videos, and problem sets.

Unsurprisingly, however, some difficulties were encountered. As pointed out by other researchers, the flipped student-centered approach to learning is a continuous process that must be refined based on the content, methods, student population, and instructor.[19] Although all students expressed high levels of appreciation for the student-centered group activities that had occurred during class, many seemed resistant to abandoning the traditional instructor-centered lecture format. In particular, many students struggled to adopt the use of recorded video materials outside of the classroom as a primary learning resource. Feedback from students about the online lessons helped guide changes that improved their usefulness for subsequent students.

The circumstances under which the curriculum was transferred to another instructor and institution (MPC) was exceptionally challenging. A community college instructor with no prior experience teaching materials was assigned the class after the semester had started, on top of an already full teaching load, at an institution that lacked materials lab facilities. Although the performance level of MPC students on the assessments was below that of COM students, they nevertheless achieved most of the learning objectives in the course. Also, the availability of the project curriculum and resources enabled delivery of a course that was essential for the transfer eligibility of most enrolled students. Moreover, by arranging a single site visit to a neighboring institution, students developed enthusiasm about the practical application of their knowledge, as well as the use of authentic engineering test equipment to evaluate materials. For some students, this experience may have reinforced their decision to pursue an engineering career, and their enthusiasm may translate into increased persistence toward degree completion.

Nevertheless, MPC students encountered significant challenges to learning from the lecture content resources and especially from the virtual approach used for some of the laboratory activities. Modifications to these resources proved successful during a subsequent implementation of the course at MPC the following year. Student attitudes regarding all course activities improved relative to the previous MPC implementation, as had all of the objective measures of student learning. In fact, although the learning gains made by students were on average still lower than in the pilot COM course, the differences were not statistically significant. Moreover, student satisfaction with the flipped lecture resources (i.e., videos and problems sets) was substantially higher than in both of the previous implementations.

The lack of materials testing equipment at MPC, and the resulting need to replace several hands-on labs in the original curriculum by virtual data analysis exercises, remained the one source of deficiency in student perceptions about their learning experience. In any future attempts to deliver the curriculum at similar institutions, additional refinements to the lab curriculum tailored to such circumstances may prove sufficient to address these shortcomings. On the other hand, it may also prove necessary for such institutions to arrange multiple site visits (e.g., two or three) in order to better accomplish the laboratory learning objectives for the course.

Finally, results from all implementations of the curriculum reinforce the findings of other researchers that the content of materials science, as compared to some other engineering courses, may require more instructor intervention during student-centered activities in order to clarify misconceptions and guide student learning.[20,21] Instructors, especially if they have little or no prior experience teaching materials science, may therefore need some training or additional resources to support their initial adoption of the curriculum.

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Appendix A. Student Survey Questions

* 1. I have reviewed the information above about confidentiality and agree to participate in this survey: yes no

Background Information

* 2. What is your gender?

* 3. What is your ethnicity/race?

* 4. How many semesters have you been enrolled in a community college, including the current semester?

* 5. How many units have you accumulated to date (including the present semester)

* 6. How many hours a week do you work (on an average week?)

* 7. If you are working, is your job related to your study of engineering (or math/physics)?

* 8. What is your job?

* 9. Why did you take the Materials course? Please choose the one response that best describes your reason for enrolling.
  The course is required for all transfer students in my major at my desired university
  Completing this course may increase my chance of being accepted into my #1 transfer institution
  Completing the course at a community college will allow me to graduate from university in fewer semesters
  I have to take the class at some point and it is less expensive to take it at a community college
  Other (please explain)

* 10. Please describe in one or two sentences what you would have done and what would have been the impact on your transfer plans if MPC had not offered the course this semester?

Effort and learning

* 11. On average, how many hours did you spend a week on the lecture and lab components of the course?
  Average amount of time spent on the lecture (including preparation and video watching)
  Average amount of time spent on the lab (including preparation and doing the lab)

* 12. Before the class started, how many hours did you EXPECT to spend on the course per week (all included, the lecture, lab, videos, etc.)

* 13. If you could start all over again and this was the only class you were taking this semester, how many hours would you spend on this course (assuming your goal was to understand all the material and do as well as possible)

The videos

* 14. On average, how much of each video lesson playlist did you watch?
  The entire lesson
  More than 75% but not the entire lesson
  50%-75%
  25%-just under 50%

Less than 25%
Other (please specify)

* 15. Did the quizzes help motivate you to be better prepared for class than you otherwise might have been?
Yes
Not sure
No

* 16. When you watched the videos did you

	Always	Sometimes	Never
Take notes			
Stop and repeat things you did not understand by scrolling back			
Write down questions you had			
Call, email or text a friend with questions about the material			
Email Professor with questions about the material			
Quickly scroll through various parts of the video to find the most important material			
Get distracted checking texts, emails, etc			
Find yourself not paying attention			

* 17. Overall, how effective would you say the videos were in helping you understand the material?
Highly effective
Effective
Not effective
Other (Please write one or two sentences to explain your answer)

* 18. What ideas do you have for how to make the videos more effective? (for example, more structure, with or without human in video, improved ability to search for particular information, ability to fast forward, more YouTube, less YouTube, etc)

The course content

* 19. During which activities did you feel you learned the most? Please rate each activity below with 5 being learned the most and 1 being learned the least.

	1 - Learned the Least	2	3	4	5- Learned the Most
Watching videos					
Reading the text book					
Reading/viewing related information I found on my own (e.g., found on the Web)					
Working on problem sets outside class					
Being in class working on problem sets					
Using the test preparation study guides					
Participating in the field trip and the lab activity at Cañada College					
Being in class listening to a mini-lecture					
Being in class completing the quizzes					
Preparing for the lab					

Doing hands-on lab activities and experiments
Completing lab data analysis and exercises

* 20. Please select one or more of the activities you rated the highest in the previous question and describe in one or two sentences what it was that made you feel you learned the most from this/these activities:

* 21. Please think back at the concepts that were introduced in the courses. Which was the hardest concept for you to understand? (for example: phase diagrams, stress-strain graphs, crystallography, etc)

* 22. Please explain in one or two sentences why the concept you identified in the previous question as most difficult to understand was challenging for you (for example:"I did not understand the diagram" or "I did not know how to apply the Lever Rule to figure out the composition of the sample")

* 23. Please rate how often you used each of the following resources outside of class to help you learn the material? (Used all the time, Used frequently, Used once in a while, Used rarely, Did not use)
Class lecture videos
Study group
Test preparation study guides
The text book
Internet search
Email or consult with Professor

Team Work

* 24. Did you work with other students in class? Always Sometimes Never

* 25. For those who worked with other students, what did you like the most about working with other students? (scale 1-5 with 1 liked the least and 5 liked the most)
I learned to work as part of a team
I learned from us having to solve problems together
I learned how to work with people who think differently from me
I learned from having to explain concepts to those who were less prepared than me
I learned from making mistakes

The LABS

* 26. Please indicate how much you agree with the following statements: (Strongly Agree, Agree, Undecided, Disagree, Strongly Disagree)
There was a strong connection between the lecture/class component and the lab activities
I had sufficient guidance on how to do the labs
I understood the learning objectives for the lab before I started the lab activity

I understood the learning objectives for the lab when I concluded the lab activity
Doing the labs made me understand the concepts that had been introduced in the videos/book
Doing the labs taught me additional skills and concepts not covered in the videos/book

* 27. Please explain in one or two sentences what you liked the most about the field/lab experience at Cañada College? If you did not participate, simply respond: "N/A -- I did not participate"

* 28. Please explain in one or two sentences how we could improve the field trip/lab experience at Cañada College for the next group of students? Again, just write "N/A" if you did not participate in the field trip.

Overall Impressions and Ideas

* 29. What did you like best about the class?

* 30. What did you like the least about the class?

* 31. What is one idea you have for how to improve the class and/or the labs?

* 32. Please use the box below to provide any additional input or feedback you have that can help us continue to improve the class and lab:

* 33. Would you recommend this class to a friend in the way it is currently offered?
Highly recommend
Recommend
Not recommend
Other (please explain):

* 34. Please explain in one or two sentences why you would or would not recommend the class to a friend.

Thank you so much for completing this survey.