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Do More Labs Lead to Increased Student Learning?

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Abstract
Background: Integrated lab-lecture courses are popular in undergraduate engineering courses as they employ the benefits of hands-on activities without the student dissatisfaction of a flipped classroom. Hypothesis: The goal of this project was to test the hypothesis that the number of hands-on activities is positively correlated with student achievement (i.e., grades). Methods: This work was done within a junior/senior-level Machine Components course. The number of hands-on, physical lab activities and overall course grades were collected from 132 students over three semesters. The correlation of these two variables was quantified using Spearman's correlation coefficient. Student evaluation scores were also analyzed better to understand the effect of hands-on activities on achievement. Results and Discussion: The number of hands-on lab activities was not statistically correlated with overall student grades for the semester, r_s = -0.16, p = 0.06. Although, this negative correlation of relative significance may support critical claims in the literature of the meshing hypothesis and suggest a more diverse range of labs (e.g., hands-on, computational) may be a better approach. Interestingly, increasing the number of hands-on activities was associated with better student ratings of the instructor's overall teaching effectiveness. This trend suggests students were more satisfied with the course overall as more hands-on experiences were added.

Keywords
active learning; kinesthetic learning; polytechnic; student satisfaction

Introduction

Engineering education has shifted from teacher-centered courses to a more student-centered approach (Catalano & Catalano, 1999; Dervić et al., 2018; Webster et al., 2016). A teacher-centered course is the traditional lecture format where an instructor orally relays information to students. In a student-centered course, lectures contain some talking by the instructor along with active exercises to get the students more engaged with the content (Smith et al. 2005), e.g. think-pair-share, where students take some time to think about a question posed by the instructor, pair up with another student to discuss their answer, and share their answer to the class (North et al., 2000).

These active learning strategies have been shown to increase student learning (Prince, 2004). For example, introducing short think-pair-share sessions into lectures significantly increased short-term student recall by 35 percent and long-term recall by 11 percent in special education teacher courses (Ruhl et al., 1987).

One common way to employ active learning in engineering courses is physical, hands-on, laboratory exercises (Carlson et al., 1999; Feisel & Rosa, 2005). For example, mechanical dissection labs can be used to teach students how function can be achieved by multiple designs of a product (Bhatnagar, 2015). Manipulatives, e.g., Legos, can be used for statics courses to help students see Newton's equation of motion (Coller, 2008). Finally, remote lab experiences can give students experience working with controllers anytime, anywhere (Jara et al., 2011).

This adoption of lab-based instruction implies a spectrum of curriculum design with varying degrees of how labs are incorporated into the scheduled class time. At one extreme, courses can be taught without labs during the scheduled class time (i.e., traditional approach). At the other extreme, a flipped classroom employing only hands-on, active learning experiences during class time with lecture videos outside of class has shown increased learning outcomes (Kerr, 2015). Although, a downside of these flipped courses is that student satisfaction or student perceptions of the course can be lower than traditional courses (Kerr, 2015; Zappe et al., 2009). Student satisfaction, as presented through course evaluations, are often used in performance evaluations of instructors, along with rank and tenure decisions (Hornstein, 2017), which makes them essential to note from a faculty viewpoint. Therefore, integrated lab-lecture courses are attractive for faculty as they employ the benefits of hands-on activities without the student dissatisfaction of a flipped classroom. When these integrated courses are refined by instructors from semester to semester, a standard adjustment at our polytechnic institution is to add more lab experiments. Since engineering students tend to be active, intuitive, visual, and sequential learners (Gaikwad, 2017), an interpretation of the meshing hypothesis (Felder, 2020) would be that adding more hands-on labs to match with this learning profile would lead to increased learning or achievement. This project aimed to test the hypothesis that the number of hands-on activities is positively correlated with student achievement of disciplinary knowledge (i.e., grades).

Materials And Methods

Machine Component Design is a course required for undergraduate Mechanical Engineering and Engineering Technology Mechanical Design majors. The course objectives are:

1. Demonstrate proficiency in fundamentals of stress analysis.
2. Design components and systems for static strength, including the use of factors of safety, failure theories, and stress concentrations.
3. Design components and systems against fatigue, including the use of endurance limit, modifying factors, fluctuating stresses, torsion, combined loading, cumulative fatigue damage.
4. Explain the design considerations in using screws, fasteners, and connections, and apply them in design problems.
5. Explain the design considerations of welded, brazed, and bonded joints and apply them to design problems.

6. Explain the design considerations of mechanical springs and apply them to design problems.
7. Explain the design considerations of gears and apply them to design problems.
8. Explain the design considerations of power transmission components and apply them to design problems.
9. Conduct and present, both written and orally, minor and major design projects.

This course is taken by juniors and seniors who have taken the prerequisite Mechanics of Materials. The class meets three times a week in two-hour sessions, totaling six hours of student-instructor contact time. Due to the size limitations of the lab space, these course sections are limited to 25 students.

Our polytechnic university embraces the concept of “hands-on, minds-on”, which translates to integrated lab-lecture courses. Therefore, the structure of each two-hour class time in the Machine Component Design course is 30 – 60 minutes of lecture and the remaining time working on hands-on lab activities (e.g., engine dissection, measuring gear ratios, valve spring testing, etc.). A single instructor has taught this course for the past three semesters using the same required textbook of Juvinall (Juvinall & Marshek, 2013). Each time, the course has been continuously improved to add more hands-on labs to increase student achievement. To assess how adding these labs has contributed to achievement, the overall course grades for each semester were downloaded from the university learning management system (Desire to Learn and Canvas). The course was curved after the first of four exams. The first exam was curved to acclimate students to the course. At this early point in the course, students are adapting to the course design, their workload for the semester, and the instructor’s testing style (e.g., the difficulty of exam problems compared to homework). This curve was done by adding points to the first exam score for all students until the class average was 85 percent on the exam. No subsequent curve or point adjustments were made in the course. Note that labs constituted 25 percent of the overall course grade for each semester.

Along with course grades, the number of hands-on labs was also recorded. A hands-on activity was defined as a lab exercise where students were physically touching a component (e.g., engine dissection) instead of a computational exercise (e.g., finite element analysis of helical compression spring). These labs were performed in groups with group lab reports submitted due to the number of physical lab setups, e.g., the number of engines available for dissection. The labs were designed to be open-ended problems where students were asked to make engineering decisions. For example, the first lab was a mechanical dissection of a small internal combustion engine (e.g., Briggs and Stratton 550 cc engine). Students were instructed to take apart the engine to isolate the piston, crankshaft, and connecting. Then, they were asked to calculate how much bearing misalignment could occur since two bearings support the ends of the crankshaft before the crankshaft breaks. This requires the students to apply their prerequisite knowledge of Mechanics of Materials in a new way, along with making assumptions about the material and modelling the crankshaft assembly (e.g., cantilever beam? Simply supported beam? Etc.).

Another example of a typical lab was measuring the pressure change in a soda can that has been shaken. Given detailed instructions, students mounted a strain gauge on a soda can and measured the voltage change when the can was shaken. Then, students were asked to calculate how this voltage related to a change in pressure. This required them to apply equations in new ways, e.g., Hooke's Law, Wheatstone bridge, and pressure vessel relations. These lab reports were then graded on their explanation and justification of the assumptions made, along with the correctness of the equations used.

To directly test the hypothesis that the number of hands-on activities is positively correlated with student achievement, the data was analyzed using traditional statistical methods (Field, 2009) with custom Matlab code (MathWorks, Natick, MA). First, statistical outliers were removed from the data. These outliers were defined as grades outside the mean course grade, plus or minus three standard deviations. Then, the grade data were tested for normality using the Kolmogorov-Smirnov test. The results of the normality test were used to choose the appropriate correlation coefficient. Spearman's correlation coefficient was used for non-parametric data (i.e., non-normally distributed) to assess the relationship between brands and the number of hands-on activities. Alternatively, parametric data (i.e., customarily distributed) was assessed using the Pearson's correlation coefficient.

Student evaluations were also analyzed to understand better the relationship between the number of hands-on labs and achievement. One question on the student evaluation asks students to rate the overall teaching effectiveness of the instructor. This is the only question in the evaluation where students give an overall rating of the instructor. The average score of this evaluation question was plotted as a function of the number of hands-on activities. Since student evaluations are largely known to reflect student satisfaction (Beecham, 2009; Hornstein, 2017), this data served as a surrogate measure of overall student satisfaction of the course. This student evaluation data may help explain any correlation, or lack thereof, between hands-on labs and achievement. However, only aggregate student evaluation was provided to the instructor; therefore, no statistical tests could be run to test the significance of the relationship between the number of hands-on activities and the teacher's overall rating.

Results

Statistical Check of Data

A total of 132 students were included in the study (
Table). One statistical outlier was removed from the course grade data. Course grades were not normally distributed, $D(132) = 1$ and $p < 0.001$.

Table 1

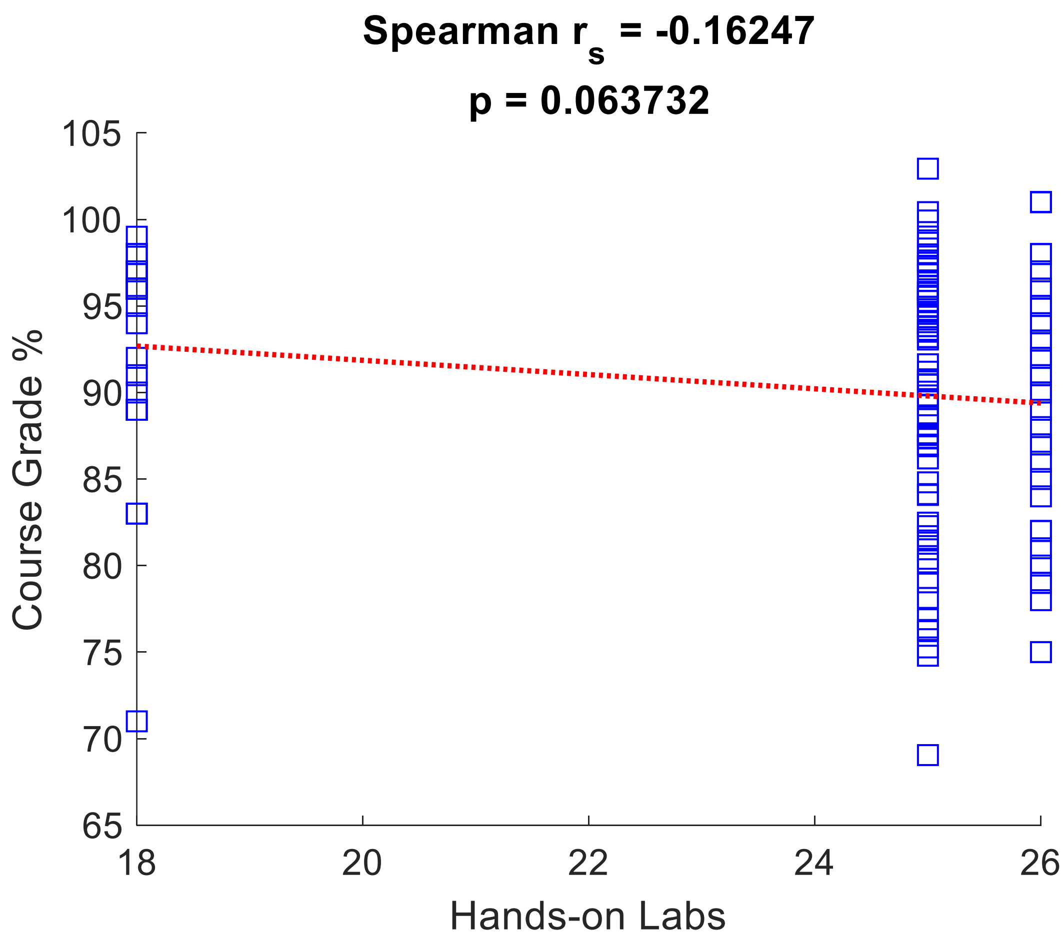
Number of students considered in data pool

Semester	Course	Number of Students
Fall 2018	ET 332	25
Spring 2019	ET 332	18
Spring 2019	ME 342	20
Fall 2019	ET 332	19
Fall 2019	ME 342	50

Correlation Results

The number of hands-on lab activities was not correlated with overall student grades for the semester, $r_s = -0.16$, $p = 0.06$ (
Figure).

Figure 1
Course grade was not significantly correlated with the number of hands-on labs.

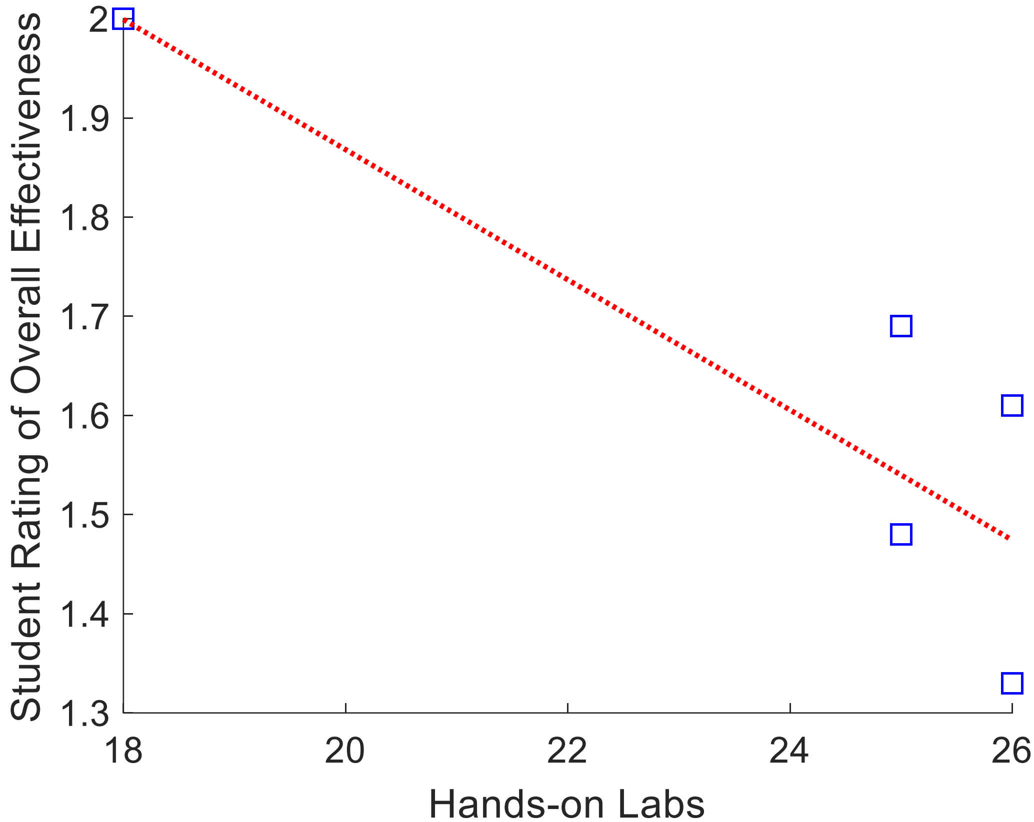


Student Evaluation Results

As the number of hands-on labs increased, the student rating of overall teacher effectiveness decreased in the numerical score (Figure 1). This student evaluation tool used a scale of one to five, where one was the best rating, a student could give the instructor and five the worst.

Figure 2

As the number of hands-on labs increased, students rated the instructor's overall effectiveness better (i.e., student rating of 1 = best to 5 = worst).



Discussion

Increasing the number of hands-on activities was not significantly correlated to student achievement, i.e., overall course grades (Figure 2). In accordance with the meshing hypothesis that matching instruction to student learning preference maximizes student learning, more hands-on activities were added to the course as undergraduate engineering students tend to be active, intuitive, visual, and sequential learners (Gaikwad, 2017). However, the nearly significant negative correlation between grades and the number of hands-on labs supports critical claims of the meshing hypothesis and suggest a more diverse range of labs (e.g. hands-on, computational) may be a better approach (Felder, 2020). Although, increasing the number of hands-on activities was associated with better student ratings of the instructor's overall teaching effectiveness (Figure). Since student evaluations are largely known to reflect student satisfaction rather than teaching effectiveness (Beecham, 2009; Hornstein, 2017), this data suggests that students were more satisfied with the course overall as more hands-on experiences were added.

There are some study design factors to consider when interpreting the data. There is little spread in the number of hands-on lab activities since data was taken from three semesters. Conversely, there was a more extensive spread in the grades. The standard deviation of the data affects the power of the statistical analysis to detect change. For example, a large spread of grades means larger correlations can be measured while smaller correlations cannot. Although, analyzing and interpreting the standard deviation of these grades was beyond the scope of this study. Also, other factors changed from semester to semester beyond just the number of hands-on activities. For example, the instructor refined their slides to provide more worked-out examples and better explain the material. Since $r = -0.16$, this means 3% of the change in grades can be attributed to the number of hands-on activities. This suggests more work is needed to elucidate better the other factors affecting these grades, e.g., the number of examples presented in lecture vs grades.

This study was undertaken as a retrospective Scholarship of Teaching and Learning (SoTL) project to reflect on changes made to the course and inform future changes. As such, this project addresses the given tenets of SoTL (Felten, 2013): (1) inquiry into student learning, (2) grounded in context, (3) methodologically sound, (4) conducted in partnership with students, and (5) appropriately public. Student achievement of discipline knowledge was quantified through course grades. Although the study was retrospective, the tested hypothesis was grounded in the meshing hypothesis of learning styles as presented in the context of (Felder, 2020). Methodologically, the data was analyzed using traditional statistical methods (Field, 2009). The instructor engaged students in this line of inquiry by soliciting feedback at the middle and end of the semesters, as well as during their capstone course. Feedback was asked about the labs: the size of lab regarding points, number of labs, quality of the lab, relevancy to lecture material, helpful for subsequent courses, etc. This feedback was used to inform subsequent labs. For example, after the first semester, students commented in Capstone that they were unable to select appropriate hardware (e.g., nuts and bolts). Therefore, a lab was added where students work with bolts they had to remove from an engine. Finally, this study could be applied across disciplines to generate more research questions. The results of this study suggest that increasing the number of hands-on activities may not lead to increased achievement; rather students were more satisfied with the course overall with more hands-on opportunities. This likely applies to other subjects as well; although more work is needed to explicitly test that hypothesis.

Ethics

The institutional review board deemed this research exempt since the work is a comparison of instructional techniques used for continuous improvement.

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