Giving Students the Keys to Their Education: Immersive Vehicle Labs In Automotive Education

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Giving Students the Keys to Their Education: A Case Study of Immersive Vehicle Labs in Automotive Education

Abstract

Automotive applications of mechanical engineering concepts continue to evolve as emerging technologies transform the automotive industry and pique the interest of mechanical engineering undergraduate students. Understanding advanced automotive engineering systems relies on students possessing a strong foundation in the various mechanical systems that make up modern automotive applications as well as the basic dynamic principles that govern automotive vehicle operation. The United States Military Academy (USMA) Department of Mechanical and Aerospace Engineering (MAE) model of teaching and learning encourages the addition of a variety of learning environments, the careful integration of technology, and hands on learning opportunities to enhance learning and inspire further inquiry. To these ends, USMA MAE elective powertrains and vehicle dynamics course relies heavily on hands-on learning opportunities whenever feasible to reinforce topics covered in the classroom and bring into focus both the testing equipment available in the automotive engineering field and the difficulties inherent to field testing.

The purpose of this paper is to analyze a case study of the impact active learning laboratory experiences have on student knowledge retention through analysis of exam data comparing topics reinforced with lab experiences to topics not currently included in the laboratory curriculum at USMA. Mechanical Engineering students enrolled in automotive engineering electives at USMA participate in several laboratory exercises that directly support their understanding of key automotive principles including tractive effort, acceleration, braking, cornering, and surface trafficability. To facilitate these lab experiences, the department has maintained a series of vehicles ranging from former BAJA SAE competition vehicles to commercial off-the-shelf utility task vehicles (UTV). These laboratory experiences reinforce classroom learning by immersing students in the topics being covered by placing them in the driver's seat in closed-course maneuvers. Completed lab experiences allow the comparison of predicted vehicle performance from fundamental design equations to actual vehicle performance.

This paper intends to provide engineering educators with analysis of a case study of the impact that immersive active learning lab experiences have on student assessment performance as well as on student feedback on the impact the labs had on their learning experience. A review of student course end feedback traces the evolution of the lab experiences to highlight useful modernization efforts over time. Overall, student feedback continues to highlight laboratory experiences as an educational and inspirational aspect of the course design.

Introduction

Active learning covers a broad range of education styles that focus on engaging students in their own learning as much as possible. Not only are students expected to participate in their learning through their presence, but they are also expected to consider what they are doing and learning throughout the educational process [1]. Previous research into active learning identified the following three methods that encourage active learning in an academic environment:

collaborative learning, cooperative learning, and problem-based learning. Collaborative learning stresses the use of small student groups working together to achieve a common goal, with an emphasis on inter-student interaction as a learning method [2]. Cooperative learning, though similar to collaborative learning, allows students to pursue a singular goal as a team while being evaluated based on individual effort, thereby preventing students from relying solely on their teammates to achieve success on the project [3]. Problem-based learning presents relevant problems early in instruction that must apply the lessons learned in coming classes to provide the setting for applying the material taught each lesson. This methodology requires increased self-directed learning to be effective but can also provide a stage for input and support from project groups to improve student motivation [1]. Students conducting self-directed learning in lab environments learn to apply the models they learn in lecture, experiment with those models, analyze their results, and learn from any failures or challenges they encounter when turning textbook concepts into physical actions [4].

Education in automotive engineering lends itself to the implementation of all three forms of active learning through daily contact with real-world applications of course material. However, clear learning objectives for active learning activities are absolutely essential to ensure the activities track with course learning objectives and set specific boundaries for students to follow during the activity [5]. A study conducted by several universities in Australia found that traditional instructional techniques improved concept understanding for undergraduate physics students vastly less than new methods of instruction focused on active learning activities and labs as shown in the graph on page 15 of “Flexible Teaching and Learning: Perspectives and Practices” by Laws, et al. Students scored over 90% on exams when instructed using active learning activities compared to averages of below 50% when instructed using traditional classroom lectures [6]. Labs and project-based learning opportunities provide students with a place to learn new material while also gaining understanding as to how the material they learn in their courses is applied to the world and how their combined knowledge as a team allows them to overcome new challenges [7]. Students respond well to labs in many mechanical engineering courses that require technical expertise to prepare them for roles in industry. Courses developed with direct input from industry such as the Fall 2018 Mechatronics offering at Southern Illinois University received student feedback lauding the lab experiences and requesting increased use of hands-on learning to improve material retention [8].

Faculty within USMA MAE implemented a series of hands-on laboratory experiences that allow students to apply the material gleaned in the classroom to problem-based questions that rely on their ability to work collaboratively and cooperatively. Each lab set clear learning objectives to ensure students understood the exercise focus and what material was being reinforced in the lab. One possible outcome of this implementation was a reinforcement of lesson material covered in the lab experiences that may have resulted in improved exam scores on material emphasized through the labs.

RQ: To what extent do active learning laboratory exercises affect student learning and exam performance on topics reinforced through such exercises as opposed to those simply covered in classroom lecture?

Background of Laboratory Execution

The current vehicle laboratory program utilizes the Polaris MRZR, a popular side-by-side Utility Task Vehicle (UTV) adapted to military service by removing the doors and adding infrared lights for use with night vision devices. While the primary vehicle used in lab experiences within these automotive engineering electives is the gasoline-powered two-seat model, both wheeled and tracked four-seat diesel-powered models also play major roles in tractive effort labs. This section lays out each lab currently utilizing the MRZR, starting with a brief description of the lab. The setup and space requirements follow, as do lab learning objectives, specific tasks required of the participants during the lab period, graded due-outs, and other tools used for the labs to collect data and enhance the lab experience. As shown in Figure 1, the labs described below have been executed in much the same form each fall term for the last nine years, though with some minor tweaks to improve data collection methodologies and student submission requirements.

	17-1	18-1	19-1	20-1	21-1	22-1	23-1	24-1	25-1
Acceleration and Braking Lab	X	X	X	X	X	X	X	X	X
Steering Dynamics and Suspension System Lab	X	X	X	X	X	X	X	X	X
Terramechanics Lab	X	X	X	X	X	X	X	X	X

Figure 1. Lab Execution by Academic Term

Acceleration and Braking Lab

The acceleration and braking lab focuses on the tractive effort, weight shift, and braking force calculations covered early in Automotive Powertrains and Vehicle Dynamics and the engine output and tractive effort elements discussed later in Vehicle Powerplants. This lab utilizes the two-seat gasoline-powered MRZR mounted with commercially available racing software from AimSport. Learning objectives for this lab include (1) calculating theoretical acceleration and braking performance based on manufacturer specifications for the vehicle and (2) comparison of theoretical values to those determined using GPS and Inertial Measurement Unit (IMU) sensor data from the mounted AimSport system.

Lab execution requires 200-300 yards of straight, paved road with enough room to turn around, even if that requires some multi-point turns. This lab also sets data points for use in later labs by measuring the vehicle trackwidth and wheelbase using tape measures and the weight, including driver and passenger, using digital vehicle scales to determine the vehicle center of gravity. Dry conditions are preferred, but weather and road conditions are elements students note in their report. Each lab group rotates through five acceleration (0-30 mph) and five braking iterations (20-0 mph). The MRZR is then parked on a slope and re-weighed to compare estimated vehicle center of gravity weight shift and balance to flat ground and depict the additional grade load.

Manufacturer engine dynamometer data provides comparison criteria against student measured data points. Additionally, students compare their data plots and calculations to other lab groups to provide a larger data pool for calculation of mean, standard deviation, and confidence intervals for their data. All data collected is submitted in a laboratory report following the department standard format.

Steering Dynamics and Suspension System Lab

The Steering Dynamics and Suspension System Lab analyzes steering systems, Ackerman angles, suspension effects, and oversteer/understeer. This lab again utilizes the two-seat gasoline-powered MRZR due to its small turning radius and ability to reuse the weight, wheelbase, and trackwidth measurements from the previous lab. Learning objectives for this lab include (1) determining the vehicle handling characteristics, (2) calculating the understeer coefficient for the vehicle, (3) identifying understeer components not related to static weight distribution such as camber thrust, and (4) the purpose of wheeled vehicle suspension system components.

Lab safety requires a relatively circular area of 100 feet in diameter. Additional equipment required for this lab includes a protractor to measure the steering angles when compared to center. Lab execution splits the groups up by circle diameter (30 ft, 60 ft, and 90 ft) and instructs groups to drive the circles at increasing speeds. Each test consists of a lap to achieve the required speed followed by three timed laps, holding the front wheels as close as possible to the painted circle. The driver then stops the vehicle at the start point with the steering wheel held at the angle required to maintain the curve at speed. Measuring the angle between where the wheels point upon stopping and straight forward provides steering angles. Lab groups submit video presentations of their findings and walk through calculations conducted. Students are asked to calculate the understeer coefficient from each speed/diameter combination, plot the steer angle against the lateral acceleration, compare oversteer/understeer to predictions from weight distribution analysis, and identify any roll steer effects.

Terramechanics Lab

The Terramechanics Lab focuses on tracked vs wheeled mobility, driving surface trafficability, drawbar pull, rolling resistance, and sinkage. This lab utilizes two four-seat diesel-powered MRZR vehicles. One MRZR is wheeled, while the other has its wheels replaced with tracks designed for use in snowy environments. Learning objectives for this lab include (1) determining experimental soil parameters using a cone penetrometer [9], (2) calculating theoretical drawbar pull and sinkage, and (3) measuring actual drawbar pull and sinkage to compare with theoretical values. Lab execution occurs at a prepared patch of either sandy or loamy soil, each provides different soil specifications and requires testing to identify soil parameters. Other equipment required includes a cone penetrometer, tow-straps, a digital load cell, and tools to re-set the soil surface between iterations.

Students utilize a cone penetrometer to calculate the remolding index. Vehicle testing consists of driving the wheeled MRZR onto the soil surface and attaching its bumper through the load cell to a solid fixed anchor point with tow straps. Initial wheel depth measurements are taken and the soil is smoothed and prepared behind the tires while the tire pressure is recorded for each tire.

With initial tension on the load cell, the driver slowly accelerates until the wheels slip, at which point the driver lets off the gas. Students measure the new sinkage depth and maximum load cell reading, iterating twice for an average. The tracked MRZR then replaces the wheeled on the soil and load cell and the test is re-run using tracks.

Submission requirements for this lab include a digital file of a presentation poster as would be built for a conference, including a short poster pitch narrative recording. The poster compares expected results from measured data to known data points given by the instructor, as well as comparing the two vehicles and their performance. Finally, students are asked to provide suggestions for improving off-road mobility for both vehicles and feedback on their lab experience.

Methods

This informal case study was conducted utilizing institutional data at USMA taken from two sources and analyzed for trends that centered on the learning impact of lab experiences. The first source is an optional Course End Feedback (CEF) survey provided to students at the conclusion of each term. These surveys provide an opportunity to anonymously criticize or praise the course and cover a range of questions that include sections specifically worded by both the institution and the department, as well as those written by course directors and individual instructors. For use in this paper, the anonymized survey results parsed open-answer feedback questions into the following three bins: labs added to material understanding, labs failed to add to understanding, and comments that did not mention the labs. This qualitative data provides insight into student reactions to active-learning experiences and how this impacted their perception of learning the course material.

The second source of data is anonymized aggregate scores on the cumulative Term End Exam that remains relatively constant each year as a consistent measure of success in the course. This consistency is driven by ABET requirements and internal desires to ensure consistency in the course material. Data, going back nine fall-term offerings of the course in question, is broken down by the content assessed by each exam portion. For analysis in this paper, the data was then agglomerated based on whether or not that topic was reinforced with laboratory experience in an attempt to identify the impact of active learning labs on material retention and application.

Results

Student Feedback on Lab Experience Educational Impact

Each course offering culminates with voluntary student completion of a course-end survey that asks both what students liked about the course as a whole and what they disliked, as well as addressing how well students feel they met the course learning objectives. Of the 71% of students enrolled who chose to response to the survey, 52% specifically referenced the lab experiences above as far and away their favorite part of the course, specifically mentioning how the labs reinforced the material covered in the classroom. Analysis of the responses from two recent offerings showed that 68% and 100%, respectively, of the total responses to course end feedback surveys indicated positive impacts on student knowledge retention and learning potential due to their participation in active-learning laboratory assignments (Figure 2).

Negative comments on labs centered around the data collection processes available for the labs and the strict grading requirements implemented by the instructors teaching the course. These comments led to revisions of the lab documents and installation of AimSport data collection hardware on one of the MRZR vehicles to better enable students to gather the data they need to analyze. Though these labs have been fixtures of this course for over a decade, course end survey data for offerings prior to AY 24 is unavailable as the system of record changed just prior to that academic year and historical submissions did not transfer between systems.

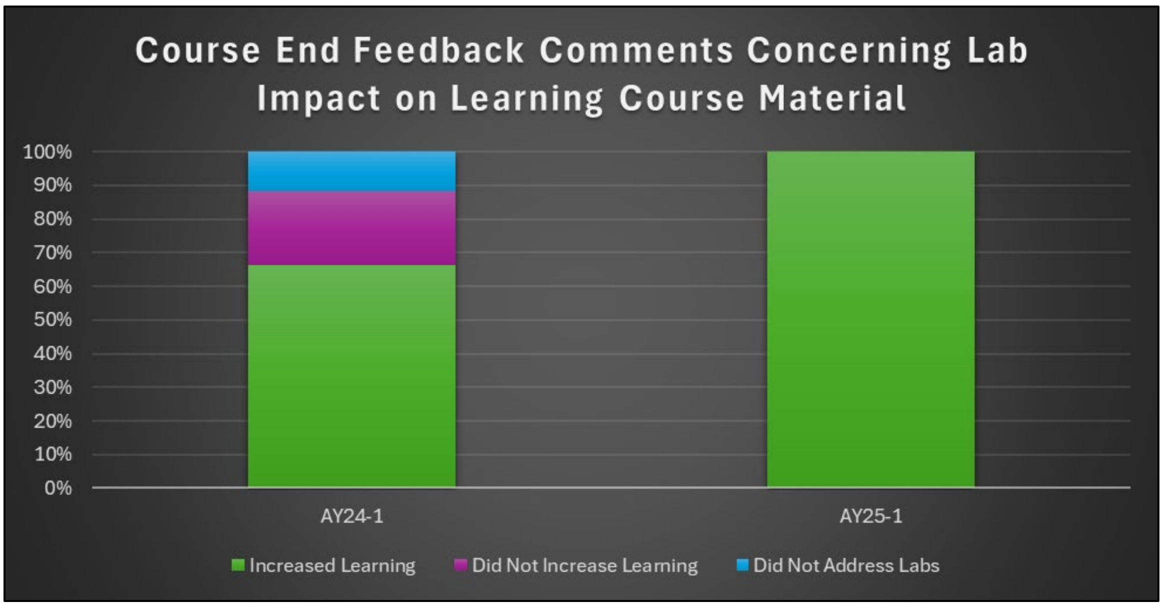

Figure 2. Course End Feedback Comments

<u>Student Exam Performance on Laboratory Topics</u>

One possible measure of the efficacy of active learning laboratory activities and the impacts they have on student learning is a comparison of student exam performance on topics elucidated in labs compared to topics not examined in laboratory experiences. Figure 3 depicts average course performance on the comprehensive final examination for the past nine years broken down between topics reinforced with labs and topics not included in labs. While labs are continually refined and improved, the impact of labs on student Term End Exam performance is inconclusive. The two most recent offerings indicate that improved lab experiences may have a positive impact of 3-5% on exam performance, but close evaluation of the evolution of current labs would be required to determine if the improved labs drove the improved scores and rule out any confounding variables

The overall data concerning exam performance is inconclusive for this case study. Performance in AY 20, AY 24, and AY 25 show promise for supporting the hypothesis that labs improve knowledge retention, but the lack of significant variation in most other offerings (less than 3%) between scores on topics covered in labs and those not covered in labs prevents a strong conclusion from being drawn. This being said, it may be worthwhile to investigate establishing new lab experiences or adapting current labs to include material covered in the course but not reinforced using labs. Modern students tend to learn more effectively through engagement and cooperation, which can be hampered when trapped in a classroom. This follows a trend noted in online engineering education as early as 2002. As the internet became more available, engineering students learning through primarily remote means without the advantage of laboratory application struggled to implement much of what they learned in real-world scenarios [10].

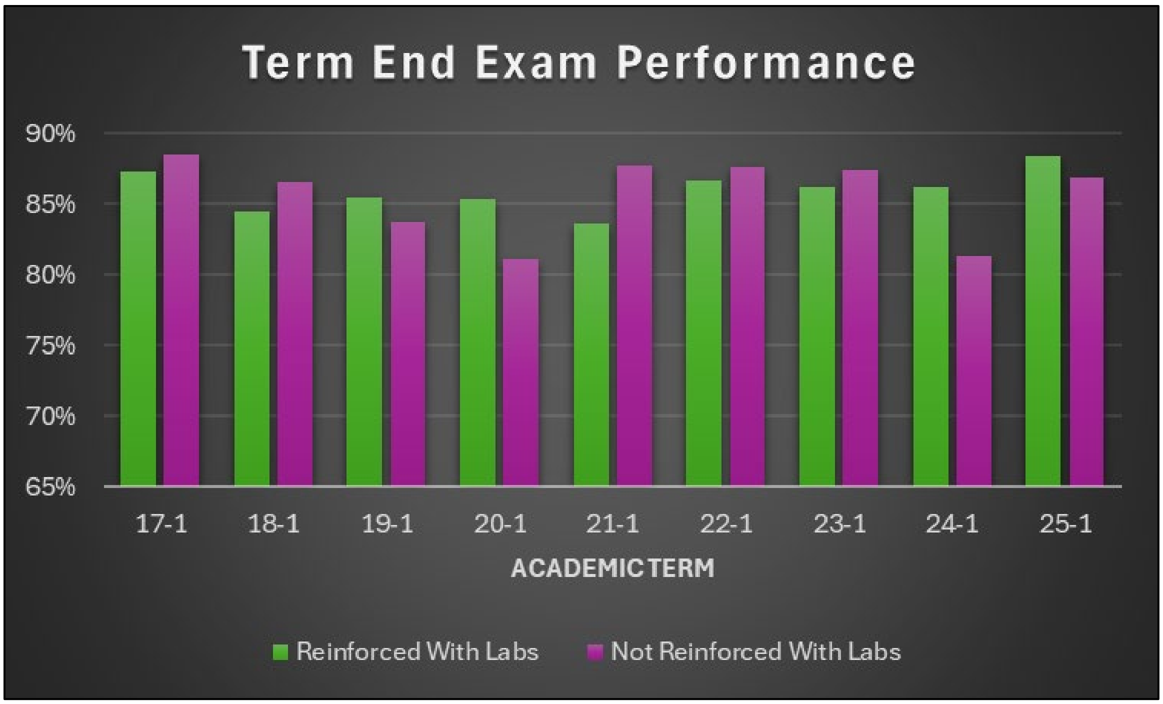

Figure 3. Term End Exam Performance by Academic Term.

Conclusion

Based on the data available, the idea that laboratory experiences improve student retention and exam performance is somewhat difficult to prove. Recent Term End Exam performance does indicate some merit to this conclusion but the data available for this case study does not demonstrate a significant trend either way. At a minimum, student feedback to lab experiences continues to be positive and indicates that mechanical engineering students enrolled in automotive electives at USMA feel that the labs improve their performance in the course and understanding of the course material. Continued positive feedback indicates openings to incorporate additional lab experiences to shift students from traditional classroom lectures to increased reliance on active experiential learning. Future development of this topic at USMA should include expanding the data analysis outside of the two automotive engineering electives within the mechanical engineering curriculum to include core courses and other electives to determine if experiential learning opportunities will increase overall student performance within the department.

References

[1] M. Prince, "Does Active Learning Work? A Review of the Research," *Journal of Engineering Education,* pp. 223-231, July 2004.

[2] A. S. Goodsell, M. . R. Maher, V. Tinto, B. L. Smith and J. MacGregor, "Collaborative Learning: A Sourcebook for Higher Education," The National Center for Postsecondary Teaching, Learning, and Assessment, Syracuse, 1992.

[3] R. J. Stahl, "The Essential Elements of Cooperative Learning in the Classroom," ERIC Clearinghouse for Social Studies/Social Science Education, Bloomington, 1994.

[4] G. D. Peterson and L. D. Fiesel, "e-Learning: The Challenge for Engineering Education," in *Proceedings of the 2002 eTEE Conference*, Davos, 2002.

[5] L. D. Feisel and A. J. Rosa, "The Role of the Laboratory in Undergraduate Engineering Education," *Journal of Engineering Education,* pp. 121-130, January 2005.

[6] P. Laws, D. Sokoloff and R. Thornton, "Promoting Active Learning Using the Results of Physics Education Research," *UniServe Science News,* pp. 14-19, July 1999.

[7] N. Lotfi, J. Novosad and H. Phan-Van, "A Multidisciplinary Course and the Corresponding Laboratory Platform Development," in *2019 ASEE Annual Conference & Exposition*, Tampa, FL, 2019.

[8] B. Maheswaran, W. Li and K. Tsering, "Motor Augment for Automotive Applications," in *2023 ASEE Annual Conference & Exposition*, Baltimore, MD, 2023.

[9] *ASTM Standard D3441-16,* West Conshohocken, PA: ASTM International, 2025.

[10] E. D. Ernst, "A New Role for the Undergraduate Engineering Laboratory," *IEEE Transactions on Education,* pp. 49-51, 1983.