Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025
ASEE
Paper ID #45640

Comparison of Dynamics Motion Capture Project Modalities

Dr. Devin R. Berg, University of Wisconsin - Stout

Devin Berg is a Professor of mechanical engineering in the Engineering and Technology Department at the University of Wisconsin - Stout.

Prof. Jesse Woodward, University of Wisconsin - Stout

Assistant Professor of Animation and Digital Media and the Director of the Motion Capture Studio at the University of Wisconsin - Stout.

Zoe Madison Cornwell, University of Wisconsin - Stout
Chloe Ferguson, University of Wisconsin - Stout

Comparison of Dynamics Motion Capture Project Modalities

Abstract

Active-learning is an eternal topic of study within the engineering mechanics education literature. Evidence suggests that active-learning can lead to better, or at least similar, student outcomes while providing for a more diverse learning environment, allowing students to demonstrate their learning in different ways. In this study, we investigated the use of motion capture technology in a dynamics course through a class project. Two different modalities were used, a marker-based motion capture system and a post-processing video analysis software. The influence on the student experience by the use of these two modalities was measured through a student experience survey. Similarly, a comparison was made between the two treatment groups based on their scores on quizzes, the project, and their course grades. The results indicate that the choice of data capture and analysis modality had limited impact on the student experience, their grades, or the project outcomes. In both cases, the students' perception of the project was positive, and the majority indicated that they found value in the experience and felt that it should be continued in future semesters. There is a tradeoff between the instructor retaining control over the experimental design, which produces more reliable results, and granting greater control to the students, which allows for flexibility in project logistics.

Introduction

In the engineering mechanics classroom, the pedagogical approach can vary widely between institutions and individual instructors. However, the use of active-learning, sometimes in conjunction with a flipped classroom approach, has become a popular mode of course delivery [1], [2]. The data available comparing various methods sometimes finds that active-learning can have positive impacts on learning [3] or student motivation [4] but there are also plenty of examples where the method of instruction and class format have limited impact on student outcomes [5], [6], [7], [8].

This study investigates whether the use of a high-fidelity motion capture lab for an undergraduate dynamics class project leads to a better student experience. Marker-based motion capture systems are commonly used in a variety of applications ranging from sports analysis and biomechanics to vibrations in industrial settings [9], [10], [11] and can provide high-precision, repeatable results [12], [13]. An alternative to these marker-based systems is video analysis and object tracking using software that can similarly provide accurate measurements in a variety of applications [14], [15], [16], [17], [18].

To evaluate and compare a marker-based system with a video analysis approach to motion tracking in an educational setting, students completed a course project as a required component of a dynamics course. The course project had two variations across different semesters. In the first variation, students recorded a video, typically using a cell phone camera, of an object undergoing motion and analyzed that motion using video annotation software capable of object tracking. In the second variation, students record a motion with a precision marker-based optical tracking system in a motion capture studio and analyze the resulting data using Excel or similar software. The basic outline of this second project modality and the use of a motion capture studio were heavily influenced by the work of Mavrommati et al. [19]. Upon conclusion of the course project, students completed a survey and answered questions about their experience.

Methods

In both variations of the course project studied here, the primary goal was for students to develop the ability to not only understand dynamics but to be able to apply their understanding to situations that they may encounter in their daily lives. Students were asked to develop a dynamics-related question for which they were interested in the answer. To answer this question, students were tasked with developing an experiment in which they captured the motion of a natural or human-made scenario and analyzed the resulting data based on the course curriculum. Finally, they communicated their findings to the rest of the class using a technical presentation.

The two variations evaluated in this study differed in the method of motion capture. In variation one, students captured the motion using a consumer-grade camera, typically a cell phone camera or an action camera. This type of video capture device provided limitations in terms of stability, resolution, frame rate, distortion, and providing only planar data capture. However, it had the benefit of being portable, familiar to use, and readily available. The video captured was analyzed using open-source software[1] to extract information about the position or orientation of objects via optical tracking. Variation two used a precision motion capture system consisting of eight Vicon Vero 2.2 cameras and reflective markers for position tracking with a mean error of 0.017 mm, as per the manufacturer[2]. The tracking data captured by this system was provided to students as a set of position coordinates and orientation of the rigid body or rigid bodies for later processing. The benefits of using the Vicon system were that it provided high-precision data with fewer opportunities for measurement error and could capture three-dimensional motion in both position and orientation. This method was limited by being confined to an indoor laboratory space and requiring the assistance of trained lab personnel to operate the equipment. The Vicon system is also considerably more expensive than the use of a personal camera. However, in our case, the Vicon system was an existing on-campus resource, used extensively by the School of Art and Design. The only additional purchase necessary was a Vicon Tracker package which included the tracking hardware, a software license for Tracker[3], and professional installation and training (from Vicon), with an engineering focus.

At the University of Wisconsin-Stout, we deployed this project across three semesters and six sections of Engineering Dynamics with a total enrollment of 130 students. Of those, three sections were assigned to the class project using the video analysis method (Fall 2023) with a total enrollment of 69 students. The other three sections were assigned the motion capture lab-based project (Spring 2024, Fall 2024) and had a total enrollment of 61 students. In both cases, the description of the project requirements was the same except for the method of data capture (motion capture lab or video). After the student groups had collected their data, some

---

[1] Kinovea, developed by Joan Charmant, https://kinovea.org/

[2] https://www.vicon.com/wp-content/uploads/2022/07/Vicon-Metrology-Solutions.pdf

[3] https://www.vicon.com/software/tracker/

supplementary instruction was provided on how to interpret the data using a spreadsheet (see Appendix A for example spreadsheets) and how to perform numerical derivatives to calculate velocities and accelerations from position data. Additionally, some instruction was provided related to plotting the data for the eventual presentation.

A survey instrument was used to gather feedback on the course and the project. Survey questions consisted of both Likert scale, rating agreement with the given statement from Strongly Disagree to Strongly Agree, and open-ended questions. The survey questions, several of which were borrowed from Mavrommati et al. [19], are provided here; open-ended questions are indicated by an asterisk.

- The format used in this course worked for me this semester.
- I would have preferred a different format for the course.
- *If you answered "Strongly Agree" or “Agree” in the previous question, please explain here. Else, please type “NA”.
- *What one thing that we did this semester do you feel most helped you to be successful in this course?
- *What one thing that we did this semester do you feel most hindered your ability to be successful in this course?
- The class project helped me think about realistic scenarios that could be tested using motion analysis technology.
- The required deliverables for the project were possible to accomplish in the time allotted.
- There are useful real-world applications for the skills gained through the class project.
- Compared to other homework assignments, the class project was more interesting and engaging.
- The project got me interested in applications of engineering related to motion analysis technology.
- This project got me interested in research.
- The class project should be repeated in future sections of Dynamics.

Responses to the Likert scale questions were compared across project modalities. These responses were evaluated for statistical significance using a two-sample Welch’s t-test.

Similarly, student scores were also collected for the two groups of students and compared across three in-class quizzes, the project score, and the overall course grade using the two-sample Welch’s t-test. For each of three quizzes, the content covered on each quiz was not explicitly tied to the conduct of the project, but rather to the course curriculum at that point in the semester. Quiz 1 covered particle kinematics and kinetics, Quiz 2 covered rigid body kinematics and kinetics, and Quiz 3 covered vibrations. These quiz scores as well as the project grade and overall course grade were included simply as measures of course performance to evaluate if the modality of the project would yield any impact on the grades received by the students rather than as a measure of student learning.

Results

The students were given the freedom of selecting the specific study topic for their course project, but instructor review and approval was used to better scope the projects for complexity, ability to safely conduct the experiment within the constraints of the measurement system used, and appropriateness to the course curriculum. The use of each of the motion analysis systems provided the students with both opportunities and challenges.

Some examples of project topics selected by students using video analysis included:

- Bicycle suspension performance versus drop height
- Change in rugby pass velocity with and without ball rotation
- Coefficient of restitution for basketball drops versus inflation pressure
- Wiffle ball trajectory off a tee versus tee height
- Influence of hockey stick deflection on puck velocity

Students found that using a video camera to capture their data provided opportunities such as flexibility of location (for example, outdoors, basketball court, or ice rink) and ease of scheduling. Challenges included difficulty in analyzing the video using the software, particularly if a non-uniform background was used. There were also some errors introduced in their analysis due to out-of-plane motion, camera motion, lens aberrations, and low frame-rate video capture.

Some examples of project topics selected by students using the motion capture lab included:

- Piston velocity versus crank angle
- Rotational velocity of a skateboard during a kickflip
- Lure velocity versus fishing rod deformation in fly fishing
- Diecast car velocity during the completion of a loop-de-loop
- Impact dynamics in bowling

The use of the motion capture lab provided more complete data, including three-dimensional position and orientation data for all tracked objects and greater precision in their data. They were limited by the size constraints of the indoor space, which provided a square floor space of approximately 20 feet on a side, difficulty with marker placement, particularly when using balls or small, light-weight objects, and issues with data loss if markers were obscured from the cameras or moved relative to each other.

Student Experience Survey: The quantitative results (n = 62 for video analysis and n = 57 for MoCap) from the student experience survey were grouped into three themes: (1) questions about the course in general, (2) questions about motion capture as a technology and its applications, and (3) questions about the project itself and its utility as a class activity.

First, students were asked two questions related to their experience in the course. These two questions were not specifically targeted at the format of the motion capture project and therefore provide limited opportunities for interpretation. However, the format of the course project was the only aspect of the course that changed between the various sections included in this study. The results shown in Figure 1 suggest that the students' general perception of the course as a whole trended in a more positive direction when the project made use of video analysis rather than the motion capture lab. From Table 1 and Table 2, this difference was statistically significant ($p<0.001$) across treatments. From the qualitative response provided to the open-ended survey questions, it wasn't clear why this discrepancy exists. For students who responded that they Strongly Agree or Agree to the questions about preferring a different course format, none mentioned the course project in their open-ended explanation for their rating. When the students were asked to identify one thing from the course that helped them to be successful, 7 out of 62 students who completed the video analysis project mentioned the project in their response. Comparatively, 6 out of 57 responses mentioned the project for those who used the Vicon system. On the other side, when asked to identify one thing that hindered their success in the class, three responses for the video analysis students and two responses for the Vicon system students identified the project. These responses indicated that difficult group mates and insufficient in-class time to work on the project were challenges that they faced.

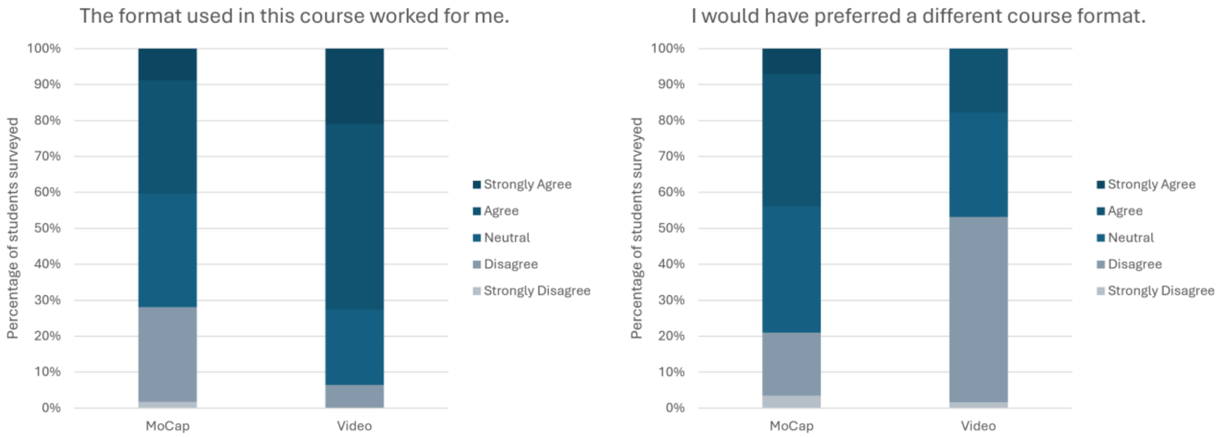

Figure 1. Survey results relating to the course experience.

Table 1. Two-Sample Welch's t-test comparing responses to "The format used in this course worked for me."

	Video	*MoCap*
Mean	3.871	3.193
Variance	0.672	0.980
Observations	62	57
Hypothesized Mean Difference	0	
df	109	
t Stat	4.050	
P(T<=t) two-tail	<0.001	
t Critical two-tail	1.982	

Table 2. Two-Sample Welch's t-test comparing responses to "I would have preferred a different course format."

	Video	*MoCap*
Mean	2.629	3.263
Variance	0.631	0.912
Observations	62	57
Hypothesized Mean Difference	0	
df	109	
t Stat	-3.920	
P(T<=t) two-tail	<0.001	
t Critical two-tail	1.982	

The next set of questions focused on the students' perceptions of the project itself, including connections made between the project and engineering applications of the technology specifically and research in general. These results are shown in Figure 2 where we can see that 87% of students agreed or strongly agreed that the project helped them think about realistic scenarios; 83% agreed or strongly agreed that there are real-world applications for the technology; 70% reported that the project got them interested in engineering applications of the technology; and 54% reported that the project got them interested in research. These results are similar to those reported by Mavrommati et al. [19]. Comparing across treatments, there is a slightly higher number of students who reported agreement with these statements from those who completed the video analysis version of the project, but the difference is not significant (*p>0.05*) as shown in Tables 3-6.

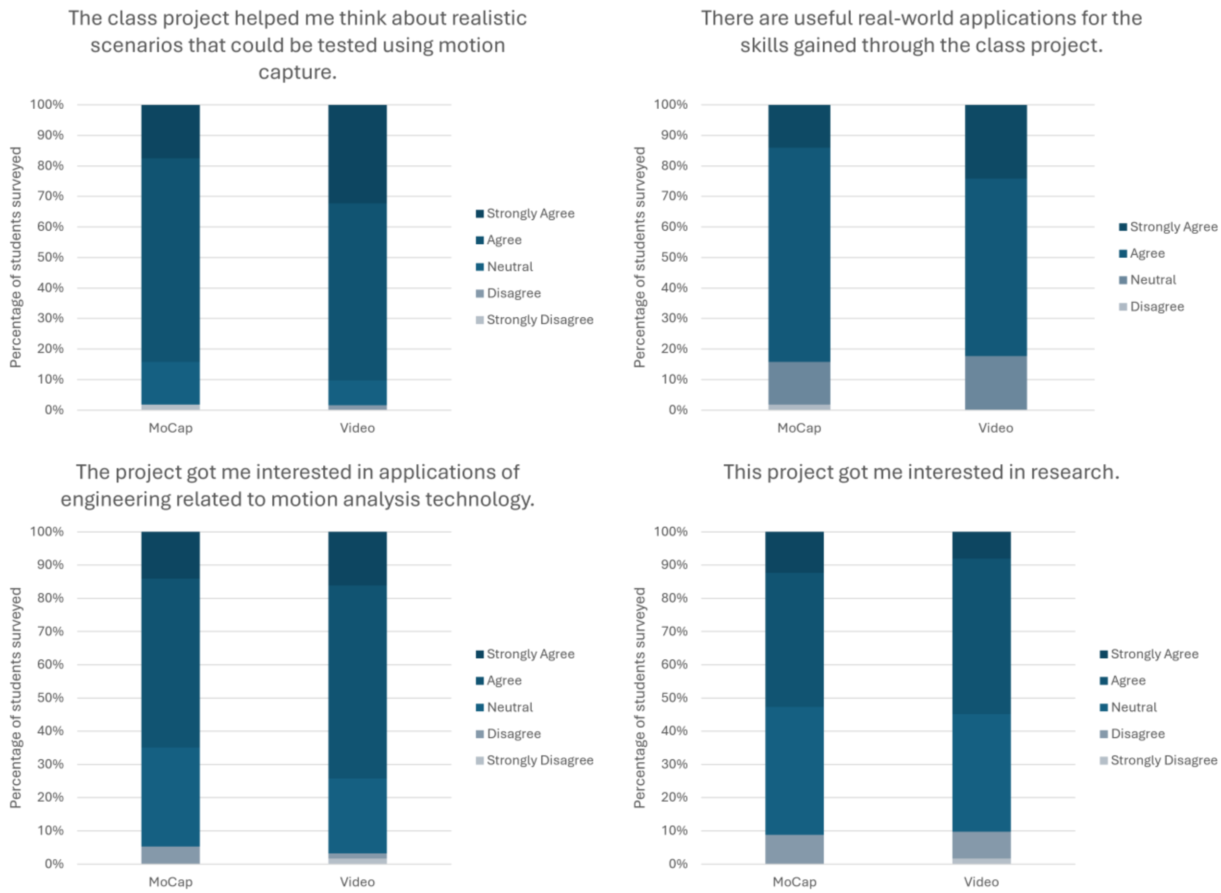

Figure 2. Survey results relating to the project experience and applications of the technology.

Table 3. Two-Sample Welch's t-test comparing responses to "The class project helped me think about realistic scenarios that could be tested using motion analysis technology."

	Video	*MoCap*
Mean	4.210	3.982
Variance	0.431	0.482
Observations	62	57
Hypothesized Mean Difference	0	
df	115	
t Stat	1.831	
P(T<=t) two-tail	0.070	
t Critical two-tail	1.981	

Table 4. Two-Sample Welch's t-test comparing responses to "There are useful real-world applications for the skills gained through the class project."

	Video	*MoCap*
Mean	4.065	3.965
Variance	0.422	0.356
Observations	62	57
Hypothesized Mean Difference	0	
df	117	
t Stat	0.872	
P(T<=t) two-tail	0.385	
t Critical two-tail	1.980	

Table 5. Two-Sample Welch's t-test comparing responses to "The project got me interested in applications of engineering related to motion analysis technology."

	Video	*MoCap*
Mean	3.855	3.737
Variance	0.585	0.590
Observations	62	57
Hypothesized Mean Difference	0	
df	116	
t Stat	0.839	
P(T<=t) two-tail	0.403	
t Critical two-tail	1.981	

Table 6. Two-Sample Welch's t-test comparing responses to "This project got me interested in research."

	Video	*MoCap*
Mean	3.516	3.561
Variance	0.680	0.679
Observations	62	57
Hypothesized Mean Difference	0	
df	116	
t Stat	-0.299	
P(T<=t) two-tail	0.765	
t Critical two-tail	1.981	

The final set of questions related to general statements about the project and its inclusion in the course. From Figure 3, we can see that 93% of respondents indicated that the time allotted to the project was sufficient; 79% agreed that the project was more interesting and engaging than other types of homework assignments; and 85% felt that the project should be repeated in future semesters. In each case, agreement was again comparable across both treatments. The widest discrepancy was in the question about time allotment, with a greater number reporting agreement for the video analysis treatment, consistent with mentions of time issues from the qualitative responses previously reported. This was the only response here which exhibited a statistically significant difference between the treatment groups ($p=0.021$) as shown in Table 9.

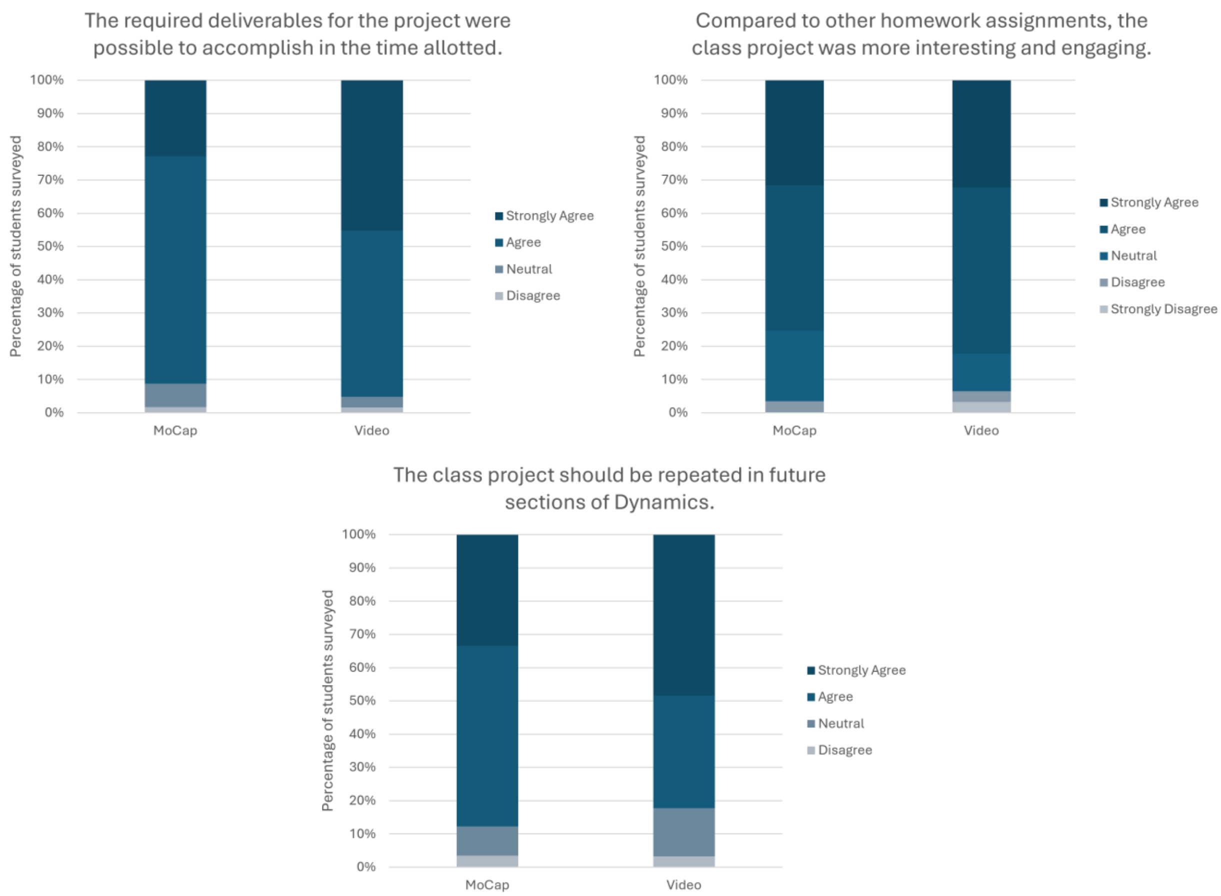

Figure 3. Survey results relating to the project experience and applications of the technology.

Table 7. Two-Sample Welch's t-test comparing responses to "The required deliverables for the project were possible to accomplish in the time allotted."

	Video	*MoCap*
Mean	4.387	4.123
Variance	0.405	0.360
Observations	62	57
Hypothesized Mean Difference	0	
df	117	
t Stat	2.332	
P(T<=t) two-tail	0.021	
t Critical two-tail	1.980	

Table 8. Two-Sample Welch's t-test comparing responses to "Compared to other homework assignments, the class project was more interesting and engaging."

	Video	*MoCap*
Mean	4.048	4.035
Variance	0.866	0.677
Observations	62	57
Hypothesized Mean Difference	0	
df	117	
t Stat	0.083	
P(T<=t) two-tail	0.934	
t Critical two-tail	1.980	

Table 9. Two-Sample Welch's t-test comparing responses to "The class project should be repeated in future sections of Dynamics."

	Video	*MoCap*
Mean	4.274	4.175
Variance	0.694	0.540
Observations	62	57
Hypothesized Mean Difference	0	
df	117	
t Stat	0.687	
P(T<=t) two-tail	0.494	
t Critical two-tail	1.980	

Controlled System Comparison: One observation made by the course instructor when reviewing project presentations and data was that measurement repeatability was a little more difficult when using the video analysis method versus the motion capture system. To further test this, three trials of the same motion, a spool rolling down and falling off the end of an incline, were captured simultaneously using the Vicon system, an action camera, a tablet, and a cell phone. Each system or device was operating at or near its maximum frame rate (resolution dependent): 300 fps for the Vicon system, 100 fps for the action camera, 240 fps for the tablet, and 60 fps for the cell phone. The video data for each of the three camera devices was processed in Kinovea, tracking the position of the spool. As can be seen in Figure 4, the data from the Vicon system provided the greatest repeatability between trials. This was primarily due to the minimal post-processing necessary after data collection. The system's coordinate system is fixed in place and the data only requires trimming of the initial and final data frames to limit the data to the period of the motion. For each of the video analysis data sets, the coordinate system had to be defined with each trial and therefore small variations were created despite using the same origin each time. Similarly, we can observe greater variation in the position tracking of the object due to drift and other errors, which were more pronounced for lower frame rate data.

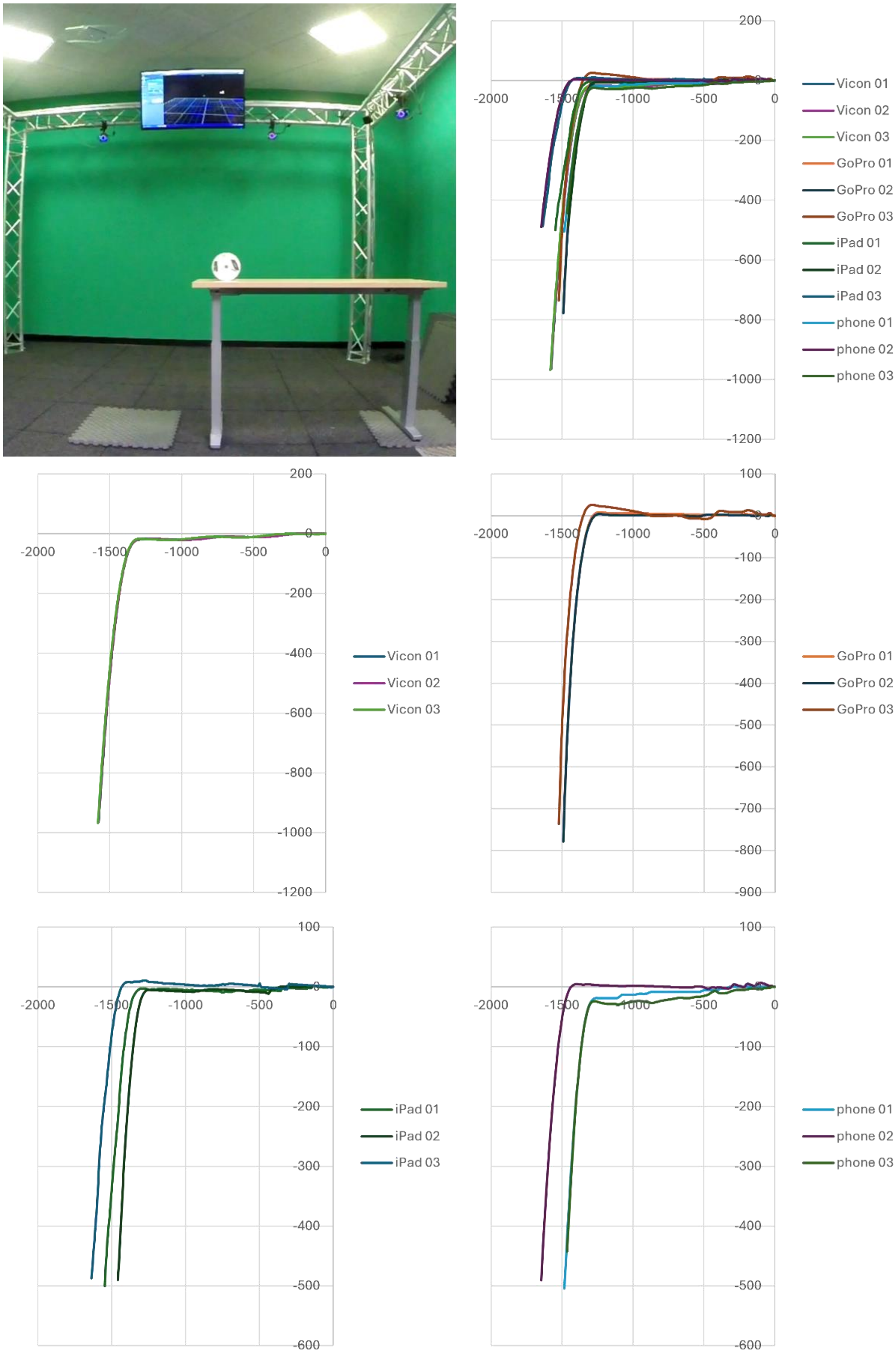

Figure 4. Motion data for an example scenario. Top-left: A spool rolling down an inclined plane. Top-right: Collected data for three trials and all four methods of data/video capture. Middle-Left: Collected data for the Vicon system. Middle-Right: Collected data for the action camera. Bottom-Left: Collected data for the tablet. Bottom-Right: Collected data for the cell phone. Axes are horizontal and vertical positions in millimeters.

Student Course Performance: The performance of the two groups of students was compared across three in-class quizzes, the project score, and the overall course grade. These results are shown in Figure 5. For each of the three in-class quizzes, the differences between the treatment groups were statistically significant as shown in Tables 10-12. The differences for Quizzes 1 and 2 were greater than for Quiz 3. It is notable that the project topics selected by the students could be accurately classified as matching the content of Quizzes 1 or 2, kinematics and kinetics of particles and rigid bodies, respectively. None of the project topics selected by the students matched the content of Quiz 3, which covered vibrations. It should be noted that deeper comparison of the quiz scores between groups may contain significant confounding factors due to variations in quiz difficulty from semester to semester.

Project scores were calculated using a rubric (see Appendix B) and the Cumulative score was calculated from the total of all points available in the course including quizzes, homework, and the project. There was no significant difference in the project scores across the groups. In the cumulative score, the Video group had a statistically significant greater average than the MoCap group ($p<0.001$). This result was primarily influenced by the differences in the quiz scores.

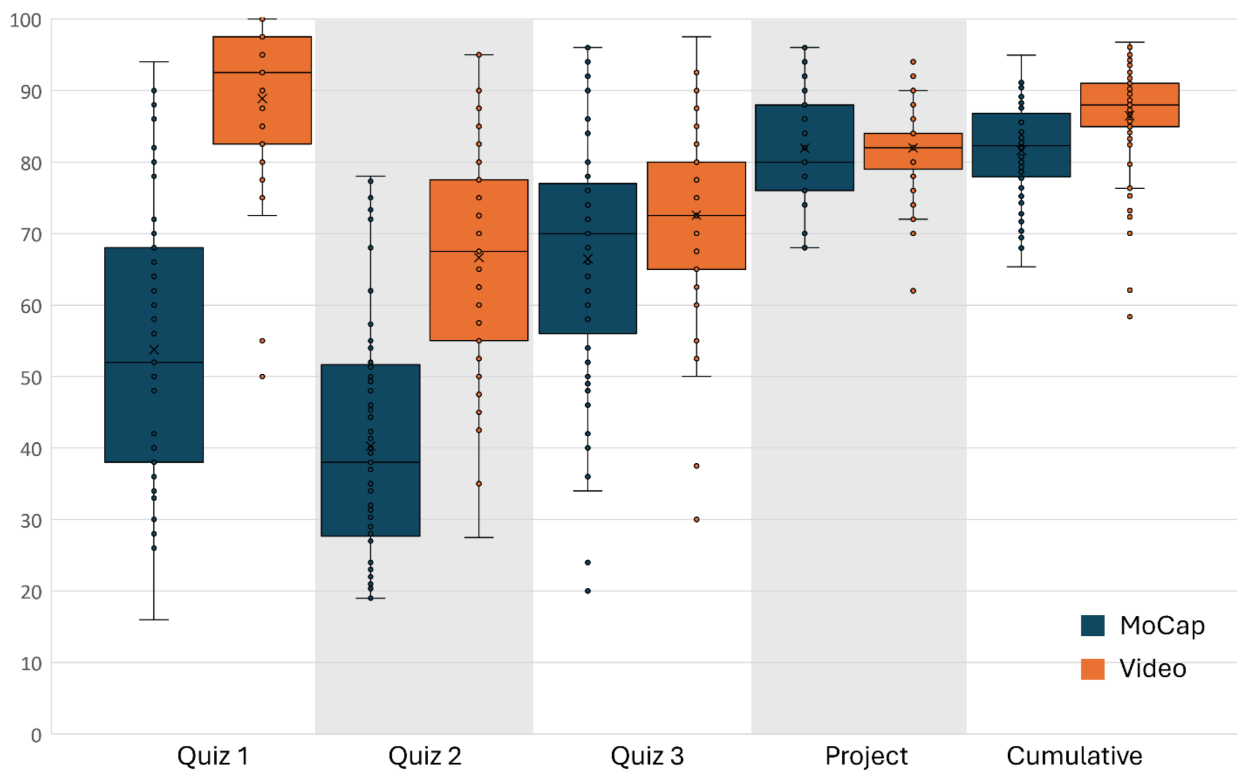

Figure 5. Comparison between treatment groups based on performance in the course. Scores are represented as a percentage of the highest possible score.

Table 10. Two-Sample Welch's t-test for Quiz 1.

	Video	*MoCap*
Mean	88.877	53.754
Variance	132.084	355.489
Observations	69	61
Hypothesized Mean Difference	0	
df	97	
t Stat	12.623	
P(T<=t) two-tail	<0.001	
t Critical two-tail	1.985	

Table 11. Two-Sample Welch's t-test for Quiz 2.

	Video	*MoCap*
Mean	66.630	40.284
Variance	200.703	258.438
Observations	69	61
Hypothesized Mean Difference	0	
df	121	
t Stat	9.856	
P(T<=t) two-tail	<0.001	
t Critical two-tail	1.980	

Table 12. Two-Sample Welch's t-test for Quiz 3.

	Video	*MoCap*
Mean	72.572	66.475
Variance	140.068	302.120
Observations	69	61
Hypothesized Mean Difference	0	
df	104	
t Stat	2.307	
P(T<=t) two-tail	0.023	
t Critical two-tail	1.983	

Table 13. Two-Sample Welch's t-test for the Project.

	Video	*MoCap*
Mean	81.971	81.934
Variance	41.117	53.862
Observations	69	61
Hypothesized Mean Difference	0	
df	120	
t Stat	0.030	
P(T<=t) two-tail	0.976	
t Critical two-tail	1.980	

Table 14. Two-Sample Welch's t-test for Cumulative Course Grades.

	Video	*MoCap*
Mean	86.485	81.623
Variance	55.845	41.256
Observations	69	61
Hypothesized Mean Difference	0	
df	128	
t Stat	3.989	
P(T<=t) two-tail	<0.001	
t Critical two-tail	1.979	

Discussion

The use of an open-ended dynamics analysis project provided students with the opportunity to explore a dynamic situation of interest to them and develop an experimental design to test a theory. Further, students were able to form connections between the course curriculum and real-world scenarios within their experience and control. Students frequently select project topics from various sports, particularly in cases where a student-athlete was on the project team. Outdoor activities such as hunting, fishing, or bicycling were also popular topics.

From the authors' perspective, the two different project formats, using a motion capture system or post-processing of a video, provided unique opportunities and challenges in both cases. The use of the motion capture system provided students with access to a high-precision tool that many would not normally be able to use. Using the system for student projects required more overhead due to the need for trained lab assistance and scheduling of lab time. However, since the system was an existing campus resource, used heavily by other degree programs, the capital expense was not significant. The repeatability of the system provided greater confidence that the data was accurate and could be used for analysis if the experimental design was well considered. However, the system was poorly suited for applications involving small or lightweight objects. The video analysis version of the project provided greater flexibility for the students. There was less overhead since no lab assistance or scheduling was required and students were able to use their personal devices for data collection. Students experienced difficulties in properly setting up an experiment while avoiding out-of-plane motion and other confounding factors, as well as the difficulty of precisely tracking objects during post-analysis, which can be influenced by camera resolution and frame rate. As a result, confidence in the accuracy of the data was lower than for the motion capture system.

Results from the student experience survey yielded only one significant difference between the two treatment groups. Students who completed the video-based version of the project had a more positive perception of the course than those who used the motion capture lab for their project. However, it is difficult to say that this difference is due to the project modality and may be better attributed to other factors outside of the scope of this study. Therefore, it is reasonable to conclude that from the student perspective, the particular modality of data capture used in this project has little influence on their experience. In both cases, the students' perception of the project was generally positive. Course performance measured by quiz scores showed statistically significant differences between the two groups. This effect was more pronounced for Quizzes 1 and 2 than for Quiz 3, which may indicate that students who completed the video project made a stronger connection to the material covered on those quizzes. The overall class grades were also different between the two groups, but it is difficult to separate this result from the Quiz scores. There was no significant difference in the project scores between the two groups. Project deliverables, evaluated using the rubric in Appendix B, showed that the students were able to attain the same level of success in meeting the desired project outcomes regardless of modality.

This project will continue to remain a part of the Dynamics course, however, there is no clear recommendation on which data capture modality is the most suitable for further use. There is some evidence that the student perception of the course was more positive if they completed the video-based project but from the instructor's perspective, confidence in the results reported by those students was lower. Dick et al. [20] and Self et al. [21] examined using predefined experiments for dynamic analysis to reduce variability and project overhead as well as to encourage collaborations with other fields both within engineering and across disciplines. Retaining greater control over the topic choice and experimental design as an instructor would indeed reduce errors in data collection at the cost of students achieving a personal connection to the project. The results here tend to indicate that students find more value in the project when they have greater over the experiment and less dependency on others. In future work, we may examine the utility of cross-disciplinary collaborations, particularly with art or athletics, which are disciplines that make use of such motion capture technologies.

References

[1] M. Hernández-de-Menéndez, A. Vallejo Guevara, J. C. Tudón Martínez, D. Hernández Alcántara, and R. Morales-Menendez, “Active learning in engineering education. A review of fundamentals, best practices and experiences,” *Int J Interact Des Manuf*, vol. 13, no. 3, pp. 909–922, Sep. 2019, doi: 10.1007/s12008-019-00557-8.

[2] R. M. Lima, P. H. Andersson, and E. Saalman, “Active Learning in Engineering Education: a (re)introduction,” *European Journal of Engineering Education*, vol. 42, no. 1, pp. 1–4, Jan. 2017, doi: 10.1080/03043797.2016.1254161.

[3] J. L. Jensen, T. A. Kummer, and P. D. d. M. Godoy, “Improvements from a Flipped Classroom May Simply Be the Fruits of Active Learning,” *LSE*, vol. 14, no. 1, p. ar5, Mar. 2015, doi: 10.1187/cbe.14-08-0129.

[4] D. I. Cordova and M. R. Lepper, “Intrinsic motivation and the process of learning: Beneficial effects of contextualization, personalization, and choice,” *Journal of Educational Psychology*, vol. 88, no. 4, pp. 715–730, 1996, doi: 10.1037/0022-0663.88.4.715.

[5] J. Liao, G. I. Papkov, A. Badir, and R. O’Neill, “A Blend Flex Engineering Mechanics Course,” presented at the 2021 ASEE Virtual Annual Conference, Jul. 2021. Accessed: Nov. 11, 2021. [Online]. Available: https://peer.asee.org/a-blend-flex-engineering-mechanics-course

[6] D. Berg, “Student Experiences with Active Learning Across Course Delivery Modalities,” *ASEE North Midwest Section Annual Conference 2023 Publications*, Jan. 2023, [Online]. Available: https://openprairie.sdstate.edu/asee_nmws_2023_pubs/2

[7] D. Berg and A. Schmitz, “Work-in-Progress: Polytechnic Perceptions of the Engineering Classroom Experience,” presented at the 2022 ASEE Annual Conference & Exposition, Aug. 2022. Accessed: Jul. 20, 2023. [Online]. Available: https://peer.asee.org/work-in-progress-polytechnic-perceptions-of-the-engineering-classroom-experience

[8] S. Koska and L. Condra, “More Time for Hands-On Learning: Flipping the Engineering Classroom in a Polytechnic,” *Proceedings of the Canadian Engineering Education Association (CEEA)*, Dec. 2018, doi: 10.24908/pceea.v0i0.12973.

[9] S. Barris and C. Button, “A Review of Vision-Based Motion Analysis in Sport,” *Sports Med*, vol. 38, no. 12, pp. 1025–1043, Dec. 2008, doi: 10.2165/00007256-200838120-00006.

[10] T. Calvert, “Approaches to the Representation of Human Movement: Notation, Animation and Motion Capture,” in *Dance Notations and Robot Motion*, J.-P. Laumond and N. Abe, Eds., Cham: Springer International Publishing, 2016, pp. 49–68. doi: 10.1007/978-3-319-25739-6_3.

[11] G.-Y. Nie, S. S. Bodda, H. K. Sandhu, K. Han, and A. Gupta, “Computer-Vision-Based Vibration Tracking Using a Digital Camera: A Sparse-Optical-Flow-Based Target Tracking Method,” *Sensors*, vol. 22, no. 18, Art. no. 18, Jan. 2022, doi: 10.3390/s22186869.

[12] J. Schmidt, D. R. Berg, L. Ploeg, and H. L. Ploeg, “Precision, repeatability and accuracy of Optotrak® optical motion tracking systems,” *International Journal of Experimental and Computational Biomechanics*, vol. 1, no. 1, pp. 114–127, 2009, doi: 10.1504/IJECB.2009.022862.
[13] V. Pourgharibshahi, “Error Analysis in Marker-Based Motion Capture Systems,” MS, Idaho State University, 2018.
[14] A. Puig-Diví, C. Escalona-Marfil, J. M. Padullés-Riu, A. Busquets, X. Padullés-Chando, and D. Marcos-Ruiz, “Validity and reliability of the Kinovea program in obtaining angles and distances using coordinates in 4 perspectives,” *PLOS ONE*, vol. 14, no. 6, p. e0216448, Jun. 2019, doi: 10.1371/journal.pone.0216448.
[15] B. Pueo, A. Penichet-Tomas, and J. M. Jimenez-Olmedo, “Validity, reliability and usefulness of smartphone and kinovea motion analysis software for direct measurement of vertical jump height,” *Physiology & Behavior*, vol. 227, p. 113144, Dec. 2020, doi: 10.1016/j.physbeh.2020.113144.
[16] N. M. N. Adnan, M. N. A. A. Patar, H. Lee, S.-I. Yamamoto, L. Jong-Young, and J. Mahmud, “Biomechanical analysis using Kinovea for sports application,” *IOP Conf. Ser.: Mater. Sci. Eng.*, vol. 342, no. 1, p. 012097, Apr. 2018, doi: 10.1088/1757-899X/342/1/012097.
[17] P. Fernández-González, A. Koutsou, A. Cuesta-Gómez, M. Carratalá-Tejada, J. C. Miangolarra-Page, and F. Molina-Rueda, “Reliability of Kinovea® Software and Agreement with a Three-Dimensional Motion System for Gait Analysis in Healthy Subjects,” *Sensors*, vol. 20, no. 11, Art. no. 11, Jan. 2020, doi: 10.3390/s20113154.
[18] T. C. G. García, M. F. B. Parada, and K. M. R. Leiva, “Biomechanical Analysis of Functional Movement in Athletes Using Kinovea,” in *Advances in Digital Health and Medical Bioengineering*, H.-N. Costin, R. Magjarević, and G. G. Petroiu, Eds., Cham: Springer Nature Switzerland, 2024, pp. 469–477. doi: 10.1007/978-3-031-62523-7_52.
[19] K. Mavrommati, E. W. Rossman, B. P. Self, and J. T. Davis, “Incorporating Motion Capture Technology in Undergraduate Engineering Dynamics,” in *2018 ASEE Zone IV Conference*, 2018. doi: 10.18260/1-2--29618.
[20] S. C. Dick, J. T. Davis, B. Wash, and B. P. Self, “Incorporating Six Pre-Defined Experiments Using Motion Analysis into Engineering Dynamics Courses,” presented at the 2019 Pacific Southwest Section Meeting, Apr. 2019. doi: 10.18260/1-2--31832.
[21] B. P. Self, S. Dick, J. T. Davis, and B. Wash, “Teaching Mechanics Concepts Using a Motion Analysis System,” presented at the 2019 ASEE Annual Conference & Exposition, Jun. 2019. doi: 10.18260/1-2--33351.

Appendix A: Example data exports

	A	B	C	D	E	F	G	H
1	Objects							
2	300							
3			Global Angle Spool01:Spool01					
4	Frame	Sub Frame	RX	RY	RZ	TX	TY	TZ
5			rad	rad	rad	mm	mm	mm
6	1	0	0.04935	-1.78874	-0.02135	1840.21	-104.841	1073.302
7	2	0	0.049284	-1.7888	-0.02138	1840.206	-104.846	1073.299
8	3	0	0.049398	-1.7887	-0.02132	1840.21	-104.838	1073.294
9	4	0	0.049284	-1.78877	-0.0213	1840.205	-104.842	1073.304

Figure 6. Example screenshot of data provided by Vicon Tracker. Data export include three rotation angles and three position coordinates.

	A	B	C
1	Time (ms)	Trajectory 1	
2	0	3764.464	
3	10	3764.463	
4	20	3764.397	
5	30	3764.262	
6	40	3764.056	
7	50	3763.777	
8	60	3763.427	

Figure 7. Example screenshot of data provided by Kinovea. Separate data exports are generated for each coordinate direction.

Appendix B: Rubric

Category	**Poor**	**Fair**	**Good**	**Exceptional**
Question/ Background	The question is difficult to understand or missing.	The question is included. Motion selected for analysis is simple/not interesting or doesn't match the course content well.	The question is well defined. Motion selected is simple but matches course content well.	The question is well defined. Motion selected is interesting and matches the course content very well.
Methods	The methods used are not described well or do not seem to be well thought out.	The methods are described in some detail but are not complete or introduce error into the analysis.	The methods are well described and will likely produce good results.	The methods are well described and account for most sources of error.
Analysis	The analysis was not performed well or missing much information.	The analysis is basic and captures the general idea of the motion. No validation.	The analysis is well throughout and seems to capture the motion well.	The analysis is thorough and includes sufficient validation to prove that it is accurate.
Results	The results are lackluster or incomplete.	The results seem accurate but are not very revealing.	The results are accurate and reveal interesting information about the motion.	The results are accurate and thorough. They are interesting and are shown to have value outside of this project alone.
Presentation	Presentation was hard to follow or poorly organized.	Presentation contained necessary content. Visuals could be improved. Some information missing.	Presentation flowed well. Visuals were adequate. Some parts were hard to understand.	Presentation included good introduction and summary. Visuals made it easy to understand the content. Was interesting.