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Project-based Learning in Dynamics: Carousel Project

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A Carousel Project for Project-based-learning in Dynamics

Abstract

Curvilinear motion analysis can be a challenging topic for beginning Dynamics students. Beyond the traditional instructional approach of reading the concepts and practicing problems from the textbook, a designed hands-on work project focusing on analyzing rotation may be a helpful learning supplement for students. Therefore, a carousel project has been developed and implemented in an undergraduate dynamics course in mechanical engineering technology (MET).

This article will discuss the learning process and results of a group laboratory project in curvilinear motion. This project is designed to not only improve students' learning outcomes and understanding of dynamics content, but also to develop and enhance their problem solving and critical thinking skills.

Students are tasked with designing and building a physical carousel model, choosing materials for the main body and supporting cables, recording data, and using their data to analyze the model's rotational motion. To solve the assigned project questions such as finding the tension, the speed, and the power, students are expected to apply their knowledge of the equation of motions, work and energy, and angular momentum in kinetics. Finally, this paper will also show the result of students' surveys on this project learning experience, the team function, and topic understanding as demonstrated through the project and analysis of the related learning outcomes from midterm and final exams.

Keywords: PBL, curvilinear motion, dynamics in MET program

Introduction

Dynamics is one of the most essential and conceptually challenging topics in studying engineering mechanics.[1] Undergraduate students in a mechanical engineering technology (MET) program normally take this course in their sophomore or junior year. The pre-requisite courses include Calculus and Statics. At many institutions, there is no corresponding lab experience. Typical lectures are comprised of textbook concepts and sample problems. The relevant course knowledge can be difficult to digest from only theoretical explanations and carefully constrained academic problems.[2] Moreover, students desire to extend their learning of these theories to real world applications, especially since many applications of dynamics link directly to fun.[3,4,5] To enhance learning interest, effectiveness, and improve critical thinking in dynamics problem-solving, a hands-on group carousel design project was launched at Purdue University Kokomo campus.

Previous semesters' assessment of course learning outcomes showed that a significant number of students had difficulty in selecting and applying the appropriate solution method when presented with curvilinear motion questions. Dynamics study deals with the accelerated motion of a body. Curvilinear motion analysis normally is more complicated than rectilinear motion to fresh dynamics learners. The carousel offers a good example for students exploring curvilinear motion as exhibited in a popular yet fairly simple amusement ride. The carousel design/build/test project has been completed by small groups of students in three weeks. By designing and building their sample carousel model, students gained hands-on experience grappling with authentic dynamics analysis concerns, resulting in self-reported increased learning interest and self-motivation for every participant. The project's objectives were articulated to the students through a series of assigned questions related to the rotation of the designed physical model. Students had to make assumptions, complete analytical calculations, and discuss the relationship(s) between their theoretical values and experiential data.

Project reports plus pre- and post- project surveys were collected from each group after three-weeks' work. In the report and the surveys, students' comments reflected their views about this project-based learning. The corresponding learning outcome results have been assessed, as well.

Students at Purdue University Kokomo campus are commuters. The typical engineering technology class has about 8-15 students and is often taught in a studio format. The campus culture tends to emphasize the efficient completion of all educational tasks performed by students.

Methodology

In this project, all nine students were second semester sophomores who previously completed statics, strength of materials, and two three-credit calculus courses. The students were assigned to three groups of three students each. This project was introduced to students after two-months' study of dynamics. Students had already learned the fundamentals of the curvilinear motion of a particle in kinematics and kinetics and conservation of energy. A pre-project survey was given on the day the project was assigned.

Students had three weeks to complete the carousel project. Steps included model building from designing to analysis to testing. 2-D (Orthographic projection) and 3-D (Isometric projection) CAD drawings of the model were required. Dimensions of height, depth and width of the model were limited to between 5 and 7 inches, with a requirement that the model would be fixed on a class-supplied base board. The body of the models were mainly 3-D printed in the university's computer lab. The weights representing four carousel seats and the connecting cables were chosen by the students, and they chose one of two kinds of dc-motor to run their carousel model.

Student groups built their models, then conducted their lab testing trials and collected all data necessary for analyzing the carousel's rotation. At the end of the three project weeks, the groups presented their carousels to the class and submitted a draft written report. Based on the instructor's review, students potentially had one more week to revise their model, update their report, and submit their post-project survey.

Limitation

The first limitation is the weight and geometry of the seat. Since this is an introductory dynamics course, students only needed to design four seats with a uniform mass between 50-100 grams each. A second limitation is the body of the model was 3-D printed using ABS filament instead of the more typically real-world choice of metal. The third limitation is the cable material. Two groups of students picked materials where they could not find the actual spring constant. They assumed a spring constant of zero in their calculations (rather than attempting to experimentally find the spring constant). The last but most critical limitation is the lack of safety constraints in the carousel designs.[6,7,8] Students mentioned safety concerns in their reports but did not do relevant calculations to ensure safe operations as part of their designs.

Project Details

A four-seat carousel model was designed, constructed and tested. The height and the diameter of the top of the model were restricted to between 5 to 7 inches. The major parts of the model were 3-D printed (printing material: ABS). Students were required to submit their design in 2D and 3D drawing form. Students chose one of two provided DC motor models: 1.5-4.5 V (27 mm height and 23.8 mm body diameter; 28 grams) and 6-14 V (32 mm height and 27.9 mm body diameter; 38 grams) (Figure 1). The material of the cable was chosen by the students (see Table 1). The weight of each seat was to be same and between 50 to 100 grams. Figures 2-4 show the model and the mass of each group's seat choice.

Figure 1: DC motor (brushed)

Figure 2: Power Supply used to drive the DC motors

Table 1: Cables and Weights for “Seats”

Group	Material	Stiffness	Mass (each seat)
1	12-lb fishing line	147.82 N/m	Fishing weights (Prism, 53 gram)
2	Unknown polymer string	unknown	Small steel plates (100 gram)
3	Fishing line	unknown	Fishing weights (Ball, 99 gram)

Figure 3: Group 1’s design (with motor at the side of the body)

Figure 4: Group 2’s carousel (with adjustable cable and motor inside)

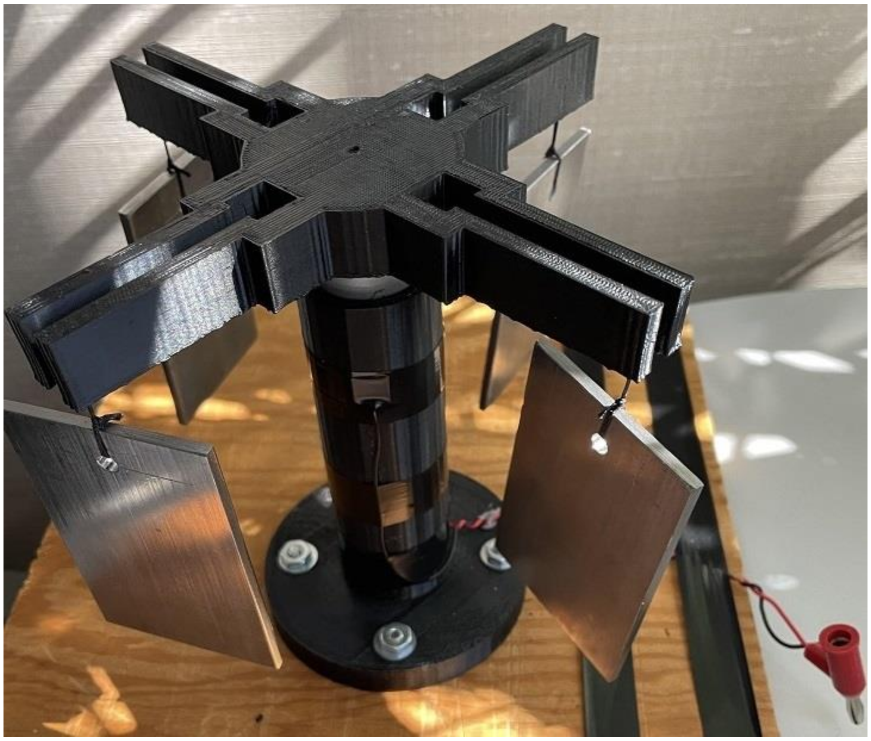

Figure 5: Group 3’s design (again, with motor inside the body)

Parts were designed and printed, then each carousel model was assembled, with joining by adhesive and screws. All the three groups used the 6-14 V DC motor. Two groups installed the motor inside the body (Figure 4 and 5) and the last group put it outside with a set of gears (see Figure 3). Finally, each carousel was mounted to a wood baseboard and made ready to test.

After turning on their model's motor, students first adjusted the voltage and let the motor run at a constant velocity. The rotational speed was recorded, allowing students to compare their calculated data to experimental data. The calculations included determining:

- Tension;
- Angular velocity;
- Power output supplied to the motor to draw the cable at constant speed;
- Angular momentum

For the next experimental condition, the cable length was shortened by one inch and the same testing was repeated to facilitate determining changes to the previously listed quantities. In addition, the students determined the amount of work done by the axial force F in shortening the radial distance.

Free-body force diagrams and kinetic motion diagrams were required elements in the students' carousel analyses.

Relevant equations[9]

Students have to determine which equations they should use to solve the questions in the project. Below is the list of equations they applied correctly to answer the questions. However, the equation list was not offered to students and they needed to work on the solution by themselves.

Students' analytical work incorporates a number of common dynamical equations. They used the equation of motion:

$$\sum \mathrm{F} = \mathrm{ma}$$

where **F** is force, **m** is mass, and **a** is acceleration; and conversation of angular momentum, $\mathbf{H_0}$:

$$(\mathrm{H_O})_1 = (\mathrm{H_O})_2$$

where $H_0 = rmv$, $v = r\omega$, $\boldsymbol{v}$ is velocity, $\boldsymbol{r}$ is the radial distance from center of rotation to the seat, and $\boldsymbol{\omega}$ is the angular velocity.

The Principle of Work and Energy equation was used to balance the kinetic energy, **T**, and the potential energy, **U**:

$$\sum T_1 + \sum U_{1-2} = \sum T_2$$

The last energy quantity for the students' analysis was power, the time derivative of the potential energy, which was calculated as the product of force, **F**, and velocity, **V**:

$$\mathrm{P} = \mathrm{F} \cdot \mathrm{V} = \frac{dU}{dt}$$

Conclusions from student reports

One group of students concluded this was a successful project. Since this project was very open ended, with the only constraints being physical size and motor choice, this meant the students really had to think about how to properly design this carousel. After a few design attempts, they were able to build a carousel that functioned well. Based on their calculations from the carousel, decreasing the radius of an object that is rotating around a fixed point clearly will increase the tension, speed, work, and power supplied if the motor is kept at the same voltage. They also were able to gain a better understanding of how gear ratios work by opting for that design choice over direct drive.

The other groups mentioned that this hands-on project was a useful supplement to the class material and helped them better understand how the course material applies to real world problems. The students also found it interesting to determine and compare the change in velocity, tension, angular momentum, and amount of work with longer and shorter string lengths. Overall, this project was complicated enough to challenge students' understanding without being overwhelming and allowed the knowledge gained from the course to be implemented in a real application.

Pre and post survey results

To gain insight into students' project perspectives and its effect on their learning and motivation, pre-project and post-project surveys with ten Likert-scale items and a few open-end questions were developed and are listed in Table 2. The Likert-scale items can be categorized as technical details, motivation, and learning. 9Student survey responses are shown in Appendix A).

The technical details items addressed students' understanding of the practical application of dynamics concepts to their carousel (tension in the cable, connection between cable length and rotational speed, angular momentum of the seats, and role of the joining method). From pre-project to post-project survey, overall, the students generally increased the level at which they agreed with the Likert-technical items or showed little change. The exception is item 3, with four students initially disagreeing and two others somewhat agreeing with the statement that the cable material will not affect the carousel's rotational speed. Based on their post-project survey responses, six students had gained insight into the interaction of cable material and rotational speed while one-third of the nine students remained confused.

Table 2: Project Survey items

Likert-learning	1. I need to review the knowledge from previous learned courses (i.e. Statics, Strength of Materials) to complete the design of this project.
Likert-Technical	2. The tension along the cable in the rotation is always in the elastic region.
Likert-Technical	3. The material of the cable will not affect the rotational speed.
Likert-Technical	4. The angular momentum of each seat about the central pole may be affected by the length of the cable.
Likert-Technical	5. The joining method of the structure may affect the performance and quality of the model.
Likert-motivation	6. Hands-on lab projects increase my learning interest.
Likert-learning	7. Hands-on lab projects improve my critical thinking skills.
Likert-learning	8. Hands-on lab projects help me to learn and understand course knowledge.
Likert-motivation	9. Working with other students on a team improves my experimental project experience (when compared to doing an individual research project).
Likert-motivation	10. Experimental research intrigues me.
Open-ended	11. Which factor(s) in the design/process may affect your final result?
Open-ended	12. Based on your design, is there any possible method to increase the rotational speed while you assuming the passengers are safe? List it for positive answer.
Open-ended	13. In real (outdoor) application, which factor(s) is (are) the most critical in the rotation compared to lab (indoor) environment.
Open-ended	14. Comments

Likert-scale items 6, 9, and 10 inform the instructors of the carousel's impact on students' motivation. All students indicated that completing a hands-on project increased their interest in learning at some level, with seven students marking Strongly Agree upon project completion. When asked about the team aspects of the project, students were less enthusiastic: one student disagreed that working in a team benefitted the project and two others marked Somewhat Agree. In the survey's Comments, a couple students noted the difficulty of completing a group project that finished during the last two weeks of the term when the campus was fully online. It is difficult to discern the role of the pandemic in these students' responses – their views of teamwork will need to be monitored to determine if this is an exceptional case or not. If this continues, instructors will need to consider ways to improve the team project experience. The final motivational item addressed student interest in experimental research (the most typical research avenue for engineering technology graduates). All students once again responded with some level of agreement, with three students marking Strongly Agree.

Learning-related Likert-scale items 1, 7, and 8 spanned continuity of learning, critical thinking, and perceptions of project-based learning approaches. 100% of the responses for these three items agreed with the listing at some level. From pre-survey to post-survey, student agreement increased for items 1 and 7, while responses to item 8 stayed essentially the same. Students recognized the need to review learning from prior courses to complete the carousel project (Item 1). Regarding the hands-on, project-based approach, all students agreed or strongly agreed that the carousel project improved their learning and understanding of course content. The insight demonstrated in their open-ended answers supports this assertion. Quoting a typical student statement, "Pretty much every aspect of the design and process will have some effect on your final result. Materials chosen, dimensions, fastening method between parts, etc, all affect final results." Similarly, most students believe this hands-on project strengthened their critical thinking skills. This was reflected in open-ended statements like "this project forced us to think hard about our design" and multiple comments about the role of safety in developing a product for public use.

Final exam assessments

Like most courses and curricula, the dynamics course at Purdue University has explicit and implicit objectives. The explicit learning objectives for this dynamics course are shown in Table 3, which also indicates assessment of student success at achieving or exceeding a mastery threshold of 70% on the final examination for the course. Fall 2020 and Fall 2018 assessment results are listed. (While the course is typically offered every fall semester, low student enrollments prevent publication of student learning objective results from fall 2019). For every one of the eight dynamics course core learning outcome objectives (CLOOs), fall 2020 students demonstrated a higher success rate than the fall 2018 students. With only one data set, it is not appropriate to attribute the increase in CLOO attainment purely to the carousel project. Please note that the nine 2020 dynamics students also completed a spring 2019 Strength of materials experimental mechanics project as well as additional projects in several other courses.[11]

Summary

This project-based instructional approach corresponds to Purdue University's overarching goals for its undergraduate programs.[11] The knowledge and experience gained through student completion of various team projects during their freshmen through junior academic years is expected to form a strong foundation for the senior capstone project (an implicit goal of most courses within the MET degree program). At the capstone level, students undertake a relatively unstructured, broadly-defined, real-world problem. Progressing from project-based to problem-based learning is facilitated through completion of the carousel project in dynamics.[12] Scaffolded problem and project learning experiences such as the carousel project increase depth of student understanding, build students' confidence in their technical knowledge, and prepare them for more substantial subsequent problem solving.

Table 3: Rate of Achievement of CLOO Success

CLOO	F2020	F2018
1.Distinguish between problems requiring a Statics solution and problems requiring a Dynamics solution (i.e., Bodies that require a Statics solution have no acceleration.)	100%	100%
2.Identify the different types of dynamics problem (i.e., Kinematics, Kinetics, Rigid Body, Particle).	79%	75%
3.Select the appropriate solution method for the different problem types (i.e., Kinematics, Equation of Motion, Work/Energy Principles, Conservation of Energy, Impulse/Momentum, and Conservation of Momentum).	71%	63%
4.Properly apply each of the solution methods.	71%	58%
5.Properly construct motion diagrams for the solution of Kinematics problems.	94%	78%
6.Properly draw supporting diagrams for Kinetics problems (i.e., Free Body Diagram, Kinetic Diagram, Impulse/Momentum Diagram, etc.).	89%	86%
7.Properly calculate the mass moment of inertia for basic and composite shapes.	44%	33%
8.Select the appropriate coordinate system type (i.e., x-y or n-t) and location for the various problem types.	92%	85%

References

1. Mikesell, D. R. and Yoder, J. S. (2011). Teaching dynamics with a design project. 118th ASEE annual conference & exposition. Vancouver.
2. Sloboda, A. R. (2015). A roller coaster project as part of an undergraduate dynamics course in mechanical engineering. 122nd ASEE annual conference & exposition. Seattle.
3. Sridhara, B. S. (2013). Course-related undergraduate projects for dynamics. 120th ASEE annual conference & exposition. Atlanta.
4. Everett, L. (1997). Dynamics as a process, helping undergraduates understand design and analysis of dynamic systems. 1997 ASEE Annual Conference. Miwaukee.
5. Helle, L. et al. (2006). Project-based learning in post-secondary education – theory, practice and rubber sling shots. Higher education. 51: 287-314.
6. ASTM. (2020). Standard practice for design of amusement rides and devices. F2291-20.
7. ASTM. (2019). Standard practice for measuring the dynamic characteristics of amusement rides and devices. F2137-19.
8. ASTM (2018). Standard practice for quality, manufacture, and construction of amusement rides and devices. F1193-18a.
9. Hibbeler, R. C. (2013). Engineering mechanics: Dynamics. Pearson Prentice Hall. Cambridge.
10. ASEE strength of materials project paper – omitted for blind review
11. University reference link – omitted for blind review
12. Anette Kolmos, Erik De Graaff. (2015). Problem-based and project-based learning in engineering education: Merging models. Chapter 11, Cambridge Handbook on Engineering Education Research.
    DOI: 10.1017/CBO9781139013451.012

Appendices

A. Group Project Questionnaire with all Likert results and Post-Project open-ended responses

Item	Strongly Agree		Agree		Somewhat agree		disagree	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
1 Project required review of previous course knowledge	1	5	5	2	3	2	0	0
2 Tension of cable stayed in the elastic region	4	5	5	4	0	0	0	0
3 Cable length does not affect rotational speed	1	1	2	5	2	1	4	2
4 Angular momentum of seat is affected by cable length	4	7	3	2	2	0	0	0
5 Joining method	5	8	4	1	0	0	0	0
6 Hands-on project increases my interest	5	7	3	1	1	1	0	0
7 Hands-on project increases my critical thinking skills	5	6	4	2	0	1	0	0
8 Hands-on project improves my learning and understanding	5	4	4	5	0	0	0	0
9 Team improved the project experience	4	5	5	1	0	2	0	1
10 Experimental research intrigues me	1	3	8	4	0	2	0	0

11. Which factor(s) in the design/process may affect your final result?

Pre-survey summary of transcribed student entries

Quoted	**Category**	Count-Student responses
A lot	Geometry/Dimension/mass	5
Weight of the parts	Design	3
Choice of cable, design idea, choice of motor, design time	Motor	4
Material selection, dimensions, joining methods, and tolerances	Material	3
Geometry, dimensions, placement of motor	Cable	3
Materials, design, motor, 3-D model quality	Join	1
Diameter of upper assembly, length of cables, mass of the cable		1

Post-survey student entries

- 3D printer constraints could limit the size of the part, which would affect angular momentum.
- Pretty much every aspect of the design and process will have some effect on your final result. Materials chosen, dimensions, fastening method between parts, etc, all affect final results.
- Material choice, method of attaching loads, placement of the motor in the assembly
- The primary process that affected the result was the way we attached the motor to the shaft.
- Many factors affect the final result. The diameter, the cable material/length, the method of rotation, the way power is transmitted all play into the final results.
- Using gear ratios vs. direct drive
- The joining of the pieces
- Simplicity
- Strength of parts
- Cable material choice
- Type and length of cable, diameter of hub piece, size of shaft
- Type of materials, motor, any reduction/step up of motor speed
- Motor, materials, friction

12. Based on your design, is there any possible method to increase the rotational speed while you assuming the passengers are safe? List it for positive answer.

Pre-survey summary of transcribed student entries

Transcribed	**quoted**	**Student response count**
Don't know		3
Change the length of the rope		3
Others	increase power	1
	Make rotation shaft more direct to motor	1
	Tight seats fit	1
	Stronger Cable	1
	Small radius	1

Post-survey student entries

- Increase the angle of the cord in relation to the center point.
- Yes, increasing the length of each cable.
- Increase amount of power supplied to the motor, increase string length
- A better gear ratio that provided more speed

- One could increase the speed directly by using a more powerful/faster motor, or by reducing the cable length. However, there will be hard limits at the point where the forces are too large for either the mechanism or the passengers.
- Increasing the voltage
- Decrease cable length
- Could get a heavier cable, so when the rotational speed increases passengers are not almost 180 °off the ground
- Increase voltage of the motor which will increase the rate of rotation
- Increase the velocity when hooked up to the power supply

13. In real (outdoor) application, which factor(s) is (are) the most critical in the rotation compared to lab (indoor) environment.

- Angular momentum because real people would be on the carousel.
- In a real world environment the biggest factors to consider is how the rotation will interact with environmental factors such as wind.
- Angular Momentum
- Power input
- In the lab, if something broke, it is not a huge deal, but in a real application, if something breaks, it could be life-threatening. So, the structure is more critical in a real setting. Additionally, environmental factors should be accounted for, such as rain, UV radiation, and thermal cycling.
- Wind
- Wind, terrain, elevation, different weights of passengers on each seat
- The ability of the motor to produce enough power to achieve desired rotational speed as well as being able to safely stop the assembly in a safe manner if emergency arises where natural slowing from friction is not acceptable.
- The material and size of cable is critical to ensure safety of the occupants.
- If the rotational speed is allowed to become too great, it is possible to subject the occupants to forces that could cause injury, therefore calculations must be done to prevent this.
- Motor being capable of withstanding the weight of the passengers and structure

14. Comments
- No other comments
- I really enjoyed this project, and I enjoyed that it was pretty open ended. This forces us to think hard about our design which is something that doesn’t always happen on projects similar to these. It also provided a better understanding as to how the calculation is affected by the radius of an object around a fixed point.

- Group project was difficult to complete the calculations due to lack of communication due to Coronavirus – not being in class to coordinate with group members.
- Having parameters such as the weight of the "seat" known before design started would improve ability to design to task at hand.
- Being in class would have helped with communication with group members.

B. DC Motor links

https://www.newark.com/velleman-sa/mot3n/dc-motor-type-brushed/dp/43W7537

https://www.newark.com/multicomp/mm18/dc-motor-type-brushed/dp/07WX1230