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# Hands-on Project Strategy for Effective Learning and Team Performance in an Accelerated Engineering Dynamics Course

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# Hands-on project Strategy for Effective learning and Team performance in an accelerated Engineering Dynamics course

**Abstract:** For many engineering undergraduate students a first course in Dynamics is often challenging when learning about the fundamentals concepts, basic Newtonian physics, and associated mathematical tools like vector algebra, trigonometry, and calculus. For educators the challenge is, motivating the students and making the learning process enjoyable. A simple hands-on activity to supplement the classroom content could greatly aid in student learning. At Rowan university an engineering dynamics accelerated course is offered every fall semester catering mainly to the sophomore students in which the content from a traditional 15-week, 3-credit class is compressed into a shorter 7.5 week, 2-credit class. For the Fall 2015 semester a project component was added to study the impact of a hands-on activity towards learning effectiveness and team work among students. Four or five member student teams conducted an air-cannon experiment based on projectile motion, energy and momentum conservation theory. The corresponding range and the time of flight was measured and compared with the theoretical values obtained from standard equations of motion therefore isolating the drag effect on the projectile flight characteristics. Each team was surveyed on how well they thought such an activity fulfilled the ABET learning objectives as well as its effectiveness on peer collaboration and team work. The survey results when compared with the final course grades shed some valuable light on the relationship between a student's perception of the effectiveness of this activity on learning, and the actual student performance on the exams. This paper will present the description and outcomes of this project in detail.

## 1. Introduction

Dynamics is universally regarded as one of the fundamental courses for undergraduate students majoring in mechanical and civil engineering among others. It is often a basic prerequisite for subsequent courses and one upon which advanced curriculum concepts are based. Since the early 1970s substantial work has gone into developing the pedagogical framework to promote conceptual understanding of the subject[1-5]. The widely followed approach is a traditional class-room lecture delivery. However this method of instruction has some serious shortcomings. Being geared more towards presenting the theoretical content in class, it fails to resolve the students' misconceptions and doubts pertaining to the real world applications of the concepts being taught. With the ever-increasing demand of curriculum expansion and inclusion of newer topics evolving on the frontiers of engineering and science, most universities are left with fewer options other than to offer condensed versions of these traditional courses. Due to time constraints the students hardly get the opportunity to 'think aloud' or 'experience the concept' that has been taught to them.

In lieu of these shortcomings, past efforts aimed at improving the instructional methodology include TST (*Tools for Scientific Thinking Motion and Force*) and RTP (*RealTime Physics Mechanics*) curriculum which focused on interactive lecture demonstrations[6], design of tutorial materials[7] student centered interactive-engagement[8-9] such as project-based learning, case-based learning, discovery learning, cooperative learning, and problem-based learning to name a few[10].

The purpose of this study is to investigate the effectiveness of including a hands-on activity in the form of a short project on student learning. It is hoped that such a study would provide valuable information about student motivation, their understanding and appreciation of the subject and hence improve student enrollment and retention into the engineering discipline. At Rowan University an accelerated version of the dynamics course is offered by the mechanical engineering department every fall semester for a period of eight weeks. The term 'accelerated' suggests that the content from a traditional 15-week, 3-credit class is compressed into a shorter 7.5 week, 2-credit class. For fall 2015 the total class size is 109, which is split into 3 sections. Each section has 3 class periods per week each of duration of 1 hour 15 mins. The entire class comprises 90% sophomore and 10% junior level students. On the basis of the present survey taken, of the 109 students 68% have three or more previous hands-on project experiences, 18% have two hands-on project experiences while 14% have only one hands-on project experience.

An experimental activity is assigned that asks the students to conduct an air-cannon experiment and compare the experimental outcomes with the theoretical prediction. A short survey is assigned as well to determine the contribution and success of such a hands-on component towards learning effectiveness and team work among students.

This paper presents an analysis of the project outcomes and the student feedback. It compares the student performance in the course with and without a hands-on component. It is hoped this paper will serve as a valuable resource to fellow academicians who are interested in bringing active and interactive engagement in the undergraduate Engineering/Technology/Science programs.

## 2. Experiment Design

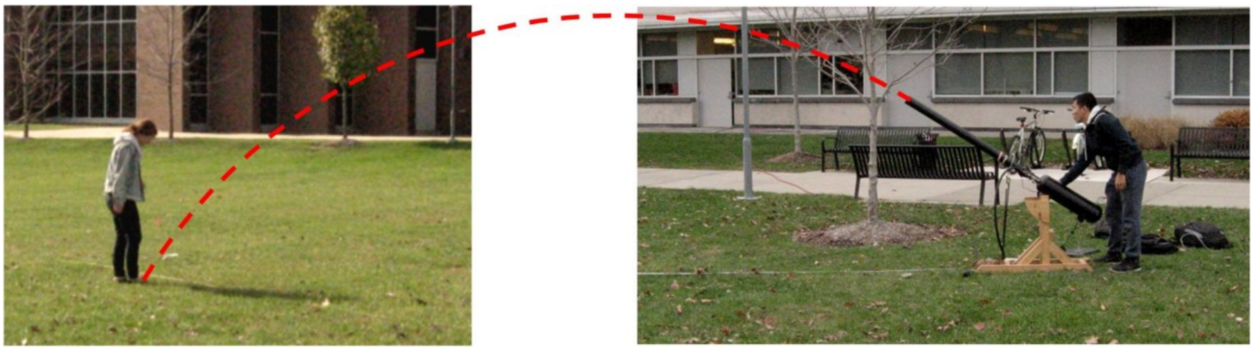

**Fig 1.** Picture of the students running the experiment

In this project the students are asked to form 4 member teams and conduct an experiment to study the projectile motion of a ball projected by an air cannon. The instructions are provided in an instruction sheet and every team runs the experiment separately with an air-canon, a stopwatch and 2 tennis sized balls of different weights. An air cannon is a device that can propel an object (e.g. a ball) in air by applying a sudden thrust caused by the sudden expansion of a gas in the cannon's barrel as shown in the schematic in Figure 2.

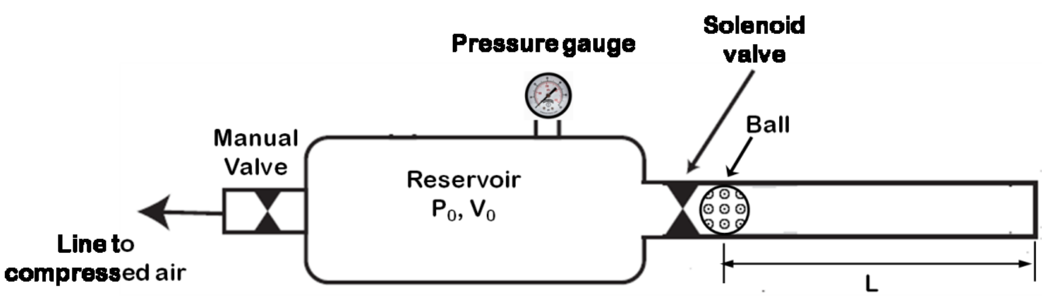


**Fig 2.** Schematic of the air cannon.

It is assumed that the expansion of air inside the air cannon is adiabatic. To some students the concepts of thermodynamic processes are familiar due to it being previously taught in their high school science courses although an in-depth understanding is usually lacking. The rest of the students were briefly acquainted to the topic based on a simplified model of a gas undergoing expansion or compression inside an adiabatic piston-cylinder system. A reason for this assumption is to let the students estimate the different losses and report the estimated values in their final submissions. The process of estimating losses within a system is taught as a lab course component in the freshmen year at Rowan. How well the students are able to account for the various losses based on physical reasoning and engineering principles would reflect their understanding of real system performance as opposed to an ideal system taught in class. If $P_0$ is the initial pressure of the reservoir, $P_{atm}$ is the atmospheric pressure, $V_0$ is the volume of the reservoir, $L$ is the length of the barrel, A is the cross-sectional area of the barrel, $f$ is the friction force inside the barrel and $m$ is the mass of the ball, then the exit velocity of the ball ($v_{exit}$) is given by Rohrbach[11]

$$v_{exit} = \sqrt{\frac{1}{m}\left(5P_0V_0\left(1-\left(\frac{V_0}{AL+V_0}\right)^{2/5}\right)-2ALP_{atm}-2Lf\right)} \qquad (1)$$

Friction force ($f$) between the ball and the cannon barrel is to be modeled by the students. The friction coefficient for rubber, PVC interface is given to be 0.5. During flight the ball experiences deceleration due to air drag and acceleration due to its weight. These forces are represented as weight $W = mg$, and air resistance (drag) $F_D = (1/2)\rho_{air}v^2C_dA_{ref}$. Here $\rho_{air}$ is the mass density of air, $v$ is the flight velocity of the ball, $A_{ref}$ is the reference area of the ball and $C_d$ is the drag coefficient between ball and air. The acceleration and deceleration values due to these forces change constantly as the velocity components change. As a result the equations of motion require a numerical solution for calculating the ball's trajectory based on equations derived by Parker[12].

The students are required to select two different pressure values and two different projection angles. The pressure values should lie in the range 40 psi - 95 psi and should be spaced at least 30 psi apart. The projection angles should lie in the range 25 degrees to 75 degrees and should be spaced at least 15 degrees apart. These values are to be repeated for two balls making a total of eight test conditions. The instructions provided with reference to the experimental setup shown in Figure 3 is as follows

**1.** Determine the mass of the ball by weighing and the volume of the reservoir by measuring.

**2.** Set the cannon to the correct projection angle.

**3.** Open the inlet valve and fill the reservoir with air at the required pressure.

**4.** Place the ball in the barrel and fire the solenoid switch. Start the stopwatch simultaneously.

**5**. Measure the distance travelled by the ball on the ground with a tape.

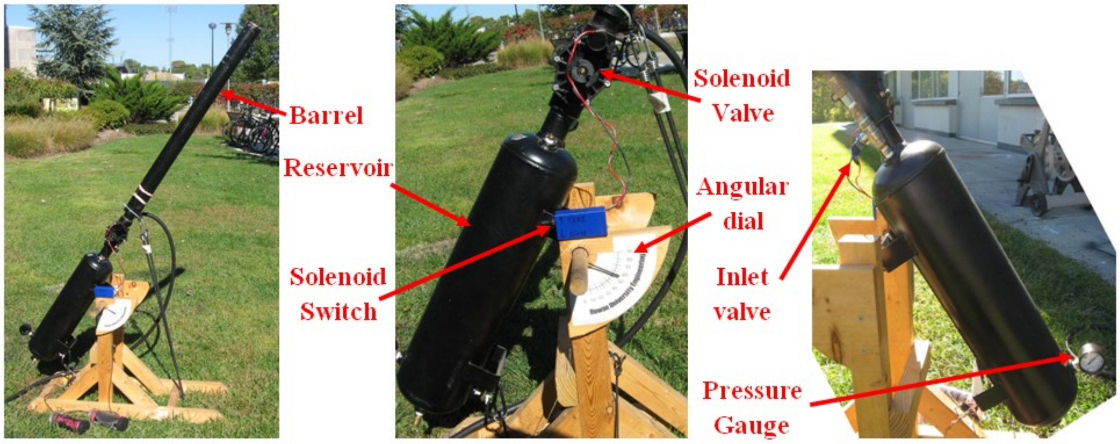


**Figure 3.** Labeled image of the air cannon setup

**3. Data analysis and reporting**

The numerical solution for calculating the ball's trajectory based on the equations derived by Parker[7] is provided to the students in the form of an excel spreadsheet wherein the students enter the values of exit velocity from (1), the projection angle, the measured range of the projectile, and the recorded time of flight. The excel VBA script outputs the X-Y co-ordinates of the drag subjected and the ideal (no-drag) flight path. The students are asked to plot the following curves **(a)** Measured Range *versus* No-drag Range **(b)** Numerically calculated Height *versus* No-drag Height and provide a suitable straight line fit to the data points for each of them.

The final reporting requirements include **(Q1)** reporting all the measured/calculated data along with the above mentioned plots **(Q2)** to report if any differences are observed in the results for the two different balls that are tested along with a scientific explanation for it. In addition the following discussion questions are asked as well.

**(Q3)** If the ball is projected with a velocity = 2000 ft/s in air how would its flight characteristics be affected?

**(Q4)** A ball projected with velocity $v$ at an angle $\theta$ breaks apart into two pieces at the highest point of its trajectory such that each piece acquires an additional horizontal velocity $v$ opposite in direction to the other piece and perpendicular to the initial horizontal direction. Find the location of each piece with respect to the launch point when it falls to the ground (Figure 4)?

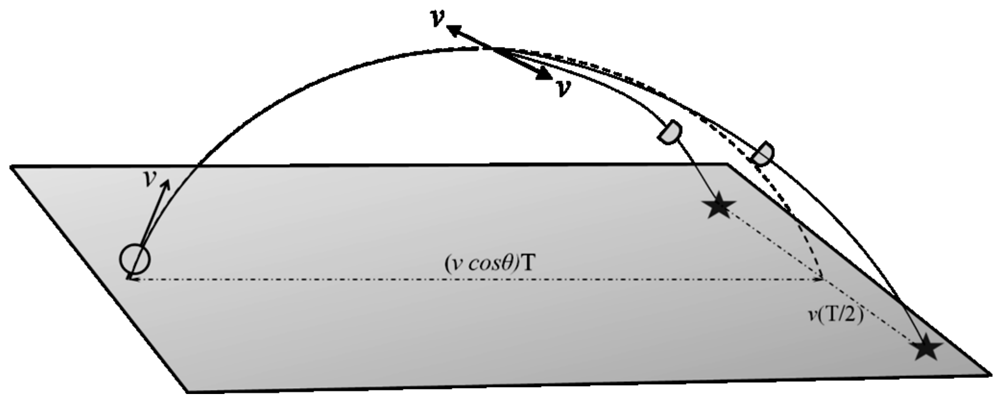


**Figure 4.** Sketch of the projectile motion for question **(Q4)**

The idea here is to probe the students' intuitiveness or make them experience the 'element of discovery' by asking about the supersonic characteristics of a projectile flight, as in question (Q3). Problem (Q4) tests their ability to solve a projectile problem using vector mechanics.

In addition to the above the students are requested to complete an optional survey based on their experience of this activity. The response to the survey does not affect their grades in any way. The motive is to get an idea of the effectiveness of this kind of hands-on activity in achieving the course objectives as detailed by the ABET guidelines. The survey questions are as follows

**S1)** How well did this experimental activity contribute towards your skills to formulate and solve engineering problems?

**S2)** How well did this experimental activity contribute towards increasing your ability to apply kinetics to projectile motion?

**S3)** How well did this experimental activity contribute towards your skills to use modern tools (numerical) for engineering practice?

**S4)** How well did this experimental activity contribute towards your ability to apply math, science and engineering principles?

**S5)** How well did this experimental activity contribute towards your skills in conducting experiment and analyzing data?

**S6)** How well did this experimental activity contribute towards your skills to function as a team?

**S7)** How well did this experimental activity contribute towards your skills to communicate effectively?

Each of the above response is scored on a 4-point Likert scale **(a)** Very much **(b)** Quite a bit **(c)** Somewhat **(d)** Very little

The last question on the survey 'What helped you most in gaining a better understanding about the experimental objectives and reporting requirements?' has the responses, **(a)** Project instruction sheet, **(b)** Class lecture, **(c)** Discussion with team members, **(d)** Textbook, online videos, other materials. The survey is elicited after the experiment has been conducted by all the groups.

Peer discussion and exchange of ideas among groups is encouraged.

## 4. Results and Discussion

The Dynamics course offered by Rowan University is an accelerated one, which compared to those, offered by similar educational institutions is uncommon because Dynamics is typically offered as a full semester 3 credit hour course. It is therefore crucial to assess the students' general performance on the course compared to how well they've perceived to have learned. This knowledge provides the impetus for developing innovative pedagogical techniques that would ensure continued success of the students in the engineering program. While classroom teaching is essential to delivering the basic principles and fundamentals of the subject oftentimes the focus shifts on providing too much information rather than ensuring that students learn the key information. The concepts covered in-class is geared towards developing the students' ability to apply theoretical knowledge to ideal situations. Hands-on, team-based engineering activities are active exercises that allow students to apply what they learn from classroom lectures to practical situations. Witnessing problems first-hand creates an awareness of the technical challenge at hand and the need to explore various solutions inorder to solve the challenge in the best possible way. Students recognize the time and resource constraints for the objectives to be met, importance of team participation and team functioning and the challenges of dealing with the discrepancies between the experimental values and theoretical values. This way they are better prepared for professional practice and careers in engineering. The present effort is evaluated on the following components (1) Students ability to design and conduct the experiment: determining the x and y components of the projection velocity, maximum height attained, and the air-drag acting on the ball during flight, (2) The team dynamics: peer assessment by the students (3) Feedback on the usefulness of this activity on student learning: obtained through the post experiment student survey. To determine if such an activity should be repeated in future classes the students are asked to provide feedback on their experiences. A qualitative analysis of the comments is included in Table 1.

**Table 1.** Qualitative analysis of the survey comments

| Response Theme | Responses in favor | Total responses |
|---|---|---|
| Discussion of project in class helps students | 4 | 31 |
| Importance of knowing how to handle the disagreement between the theoretical values and experimental values | 10 | 31 |
| Importance of contributing positively to the team's effort | 48 | 64 |
| Importance of fulfilling team roles and duties as assigned | 46 | 64 |
| Importance of communicating well with team members | 52 | 64 |
| Importance of being able to meet team expectations | 61 | 64 |

Based on the comment themes in Table 1, one can clearly see that the response theme from students are mainly centered around team work, their individual team roles and effective team communication, more so than the technical aspects of the project.

Some of the feedback comments in support of the positive impact of such an activity on the learning experience include,

*Fun and interesting project, had a good experience with this team.*

*It supplied valuable engineering lessons in that oftentimes calculations do not work out in the planned way. In addition, asking questions is vital to success in engineering and that was excellently displayed in this project.*

*Overall the project was helpful in expressing the material of drag force. I enjoyed the experimental part of this lab.*

The feedback comments pertaining to the impact of team dynamics on the accomplishment of this activity include,

*Out of all of my group members, NC contributed the most to this project by far. The other group members helped when needed, but out of my three group members, NC did the most work.*

One particular comment points to how lack of team co-ordination and communication might affect the task's success, *I was very unsatisfied with this project mainly because two of my team mates literally did nothing.*

Another student comments on his satisfaction with this project in the following way,

*All members fulfilled their requirements effectively and within a timely manner. The experiment was not too complicated to be preformed effectively and the report was well written.*

Other feedback comments are related to the division of task among team members, planning and execution as well as their understanding of the technical challenges of this activity as a whole. Specific comments by students point to the fact that students are appreciative of each other's efforts by and large, as is also evident from Table 1.

The peer evaluation component was included in the survey and serves as a teamwork assessment instrument. Every student has to enter the names of his/her team members and evaluate them by applying a tick under the relevant category. The categories are

1. Failed to meet team expectations
2. Fulfilled team role duties as assigned
3. Contributed positively to the team's effort
4. Communicated well and organized team activities

The results have already been presented in Table 1.

It is of interest to know how the scores obtained on the hands on activity compare with the grades obtained on the course as a whole. This is of interest because the project contributes merely 25% towards the final course grade. Figure 5 shows the grades received on the project compared to the average final course grade for each team. The grading rubric for the project has been described in the Appendix, Table 1. A total of 17 teams are considered. The x-axis category denotes the team names. Teams J, L and N exhibit the most variation between the project grade and the final course grade. The mean grade (out of 100) on the project = 91.29 and the standard deviation for this set is = 3.73, the mean final course grade = 85.32 and the standard deviation = 15.14. This is conceivable because of the difference in the scope of evaluations between the hands-on project component and an engineering dynamics course as a whole. While the grading rubrics on the project are focused on evaluating reporting skills, writing skills, experimentation skills and conceptual thinking the final course grade depends on the performance on final exam, homework and quizzes. Here the rubrics are based on theoretical aspects of problem solving. Another reason is a group evaluation on the project versus an individual evaluation on the final course grade. Even though every effort was made to maintain consistency in grading, the grades assigned by different course instructors may still be a minor weighing factor if not a major one.

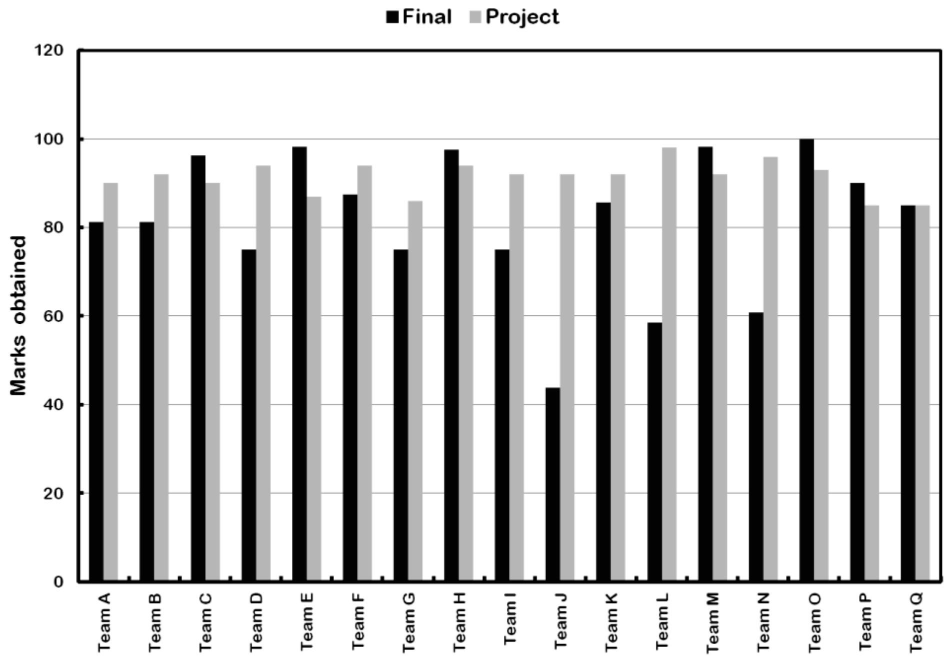


**Figure 5.** Comparison between the project grades and the average final course grades for 17 student groups

Table 2 shows the mean grades obtained on three most basic rubric components as scored on the final exams (out of 100) alongwith how well the student perceive the hands-on activity contributes towards the development of respective skill set (obtained via survey). The rubric components are (a) Ability to apply kinetics to projectile (b) Ability to formulate and solve engineering problems (c) Skills to communicate effectively. One may point to the likelihood that the students probably under-estimated their ability to apply kinetics to projectile motion. On the other hand their ability to formulate and solve engineering problems is not well represented by their response.

**Table 2.** Final exam grade obtained on three most basic rubric components alongwith the student perception of how much the hands-on activity contributed towards the respective rubric skill set.

| **Source** | | **Ability to apply kinetics to projectile** | **Skills to communicate effectively** | **Ability to formulate and solve engineering problems** |
|---|---|---|---|---|
| Final exam grade | Mean | 84.20 | 73.0 | 54.20 |
| | Stdev | 1.18 | 1.01 | 1.20 |
| Survey | Quite a bit | 18% | 28% | 20% |
| | Somewhat | 39% | 47% | 52% |
| | Very little | 38% | 17% | 23% |

Table 3 shows the mean course grade for the years 2015 (with hands-on component), 2013 and 2012 (without hands on component). Little change is observed in overall student final grade with or without project components. A student t-test is conducted between the final grades obtained in the years 2015-2013 and 2015-2012. The difference observed is not significant between any class years, yet there are many variables that are different for each course offering. For example between 2015 and 2012/2013 the class-size was different, different instructors taught the course and the course material covered was slightly different. Besides the overall academic abilities of students has improved successively each year as well.

**Table 3.** Mean course grade for 2015, 2013 and 2012.

| Year | Mean Final Grade | Standard Deviation | Number of Students |
|---|---|---|---|
| 2015 | 85.32 | 15.14 | 109 |
| 2013 | 86.11 | 12.85 | 66 |
| 2012 | 82.97 | 7.85 | 48 |

In addition to the above observations as per the response to the survey questions (Figure 6) 76% of the class support the thought that this activity benefits their learning in a positive way. However there is no data at present to validate this statement other than the survey data. It would be of interest to validate the student perceptions against some kind of performance metrics. Figure 6 reports the student responses to questions S1-S7 on the survey based on ABET guidelines as mentioned earlier. Based on the responses 4% of the students find this activity extremely useful, 27% find it quite a bit useful, 45% find it somewhat useful while for the remaining 24% this activity makes no difference. According to the feedback comment the large difference in the theoretical value of the projection velocity obtained by equation (1) and the actual value of the projection velocity, either due to incorrect modelling of the friction force or not accounting for the cannon losses (e.g. valve losses) is a critical factor in decision making. This can be remedied by discussing the project more in class as one student correctly pointed out.

*The project was not clearly explained. Project should have been discussed more in class.*

For some junior level students this kind of activity overlaps with one of their previous projects where they launch bottle rockets and essentially follow a similar procedure, as is obvious by one of the comments

*This project is outdated. I think it is time to move on from projectile motion unless we are going to really look at drag and aerodynamics.*

One of the most challenging aspects of this hands-on activity is the difficulty experienced by the students in matching their analysis to the observed values. From the feedback it could be inferred that it is daunting for some students to handle this discrepancy. Even though estimating drag losses is a part of the objective of this project there are other types of losses present in the system which is not taken into account. The students are however asked to discuss this in their report.

The response to the last question on the survey 'What helped you most in gaining a better understanding about the experimental objectives and reporting requirements?' has the following distribution: Project instruction sheet - 38%, class lecture - 11%, discussion with team members - 34% and textbook, online videos, other materials - 17%. This is indicative of the fact that peer interaction is certainly one of the most critical factors in effective learning.

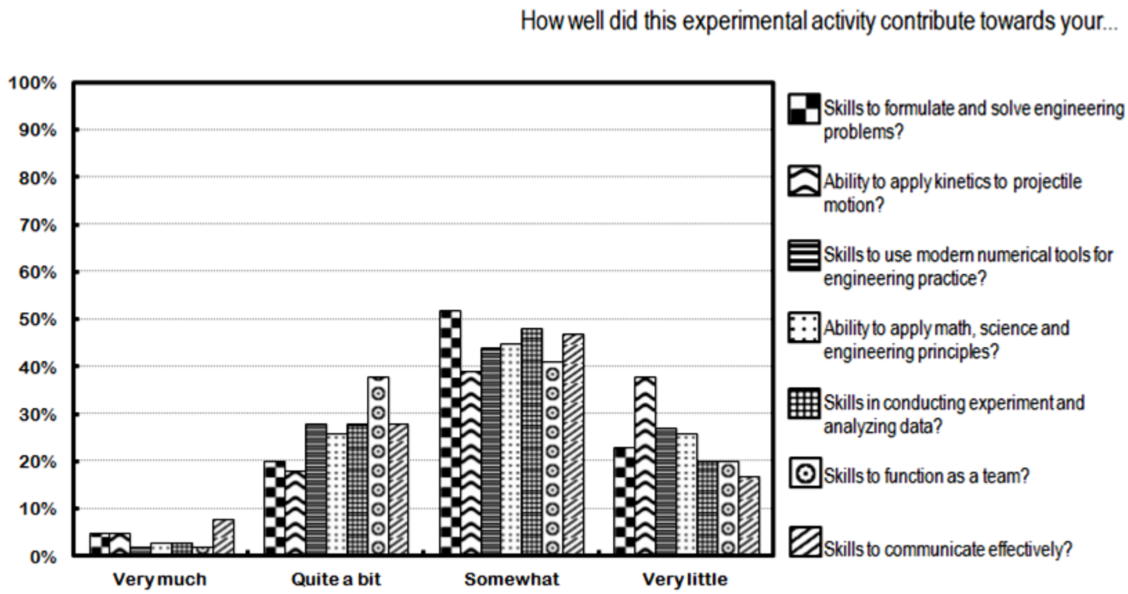


**Figure 6.** Histogram plot of the response to the survey questionnaire.

## 5. Conclusion

At Rowan University a project component was added to the engineering dynamics accelerated course to investigate the impact such kind of a hands-on activity would have on learning effectiveness. The students were asked to form 4 member teams and conduct an experiment on the projectile motion of a ball projected by an air cannon. The scoring scheme for this project activity was based on a rubric designed to assess ABET student outcomes and team work. On the basis of the survey response more than ¾ of the class felt that this activity benefited their learning in a positive way while more than ⅓ of the class found the project instruction sheet as well as discussion with team members to be the most helpful to them. However it would be desirable to validate this data with some kind of performance metrics. It is difficult to draw a definite conclusion by comparing the scores obtained on the hands on activity with the grades obtained on the course as a whole mainly because of the difference in the scope of evaluations between the hands-on project component and an engineering dynamics course as a whole. Based on a comprehensive analysis of the student responses the majority of the comments pertain to team work, team roles and communication, more so than the technical aspects of the project. Little change is observed in overall student final grade between the years 2015, 2013 and 2012 with or without project components. A student t-test conducted between the final grades obtained in the years 2015-2013 and 2015-2012 did not observe any significant difference. However there are other factors that need to be accounted as many variables are different for each year the course was offered. These factors include different class-sizes, different instructors, their teaching styles and effectiveness, different amount of course material covered and the improvement in the overall academic abilities of students successively each year.

Some of the suggestions to improve such kind of studies is the inclusion of additional tools and validation schemes such as CATME, extension of the hands on active learning approach to other topics in dynamics, better comparison between a non-lab and a lab based dynamics course, and an even greater amount of data accumulation over a significantly longer period of time (more than 5 years). Some of the other areas that need to be addressed are (1) a detailed explanation of the project in class, (2) introduction of slight complexity to the project so as to engage the advanced level students in the class and (3) teaching the students how to handle the discrepancies between their analytical results and observed values due to the various losses accompanying any physical phenomena.

## References


[1] Busch-Vishniac, I., Kibler, T., Campbell, P. B., Patterson, E., Darrell, G., Jarosz, J., Chassapis, C., Emery, A., Ellis, G., Whitworth, H., Metz, S., Brainard, S., Ray, P. 'Deconstructing engineering education programmes: The DEEP Project to reform the mechanical engineering curriculum.' *European Journal of Engineering Education*, 36, 2011.

[2] Karplus, R., and Their, H.D., 'A new look at elementary school science.' Rand McNally and Company, 1969

[3] Boylan-Ashraf, P.C., Freeman, S.A, Shelley, M., 'A Case For a Reform in Teaching Introductory, Fundamental Engineering Mechanics Courses', *121st ASEE conference, Paper ID #9483*

[4] Rompelman, O. and De Graaff, E., 'The engineering of engineering education: curriculum development from a designer's point of view.' *European Journal of Engineering Education,* 31(2), 2006

[5] Walkington, J. 'A process for curriculum change in engineering education.' *European Journal of Engineering Education*, 27(2), 2012

[6] R.K. Thornton and D.R. Sokoloff, 'Assessing student learning of Newton's laws: The Force and Motion Conceptual Evaluation and the Evaluation of Active Learning Laboratory and Lecture Curricula' *American Journal of Physics* 66 (338), 1998.

[7] L.C. McDermott, P.S. Shaffer, and M.D. Somers, 'Research as a guide for teaching introductory mechanics: An illustration in the context of the Atwood's machine', *American Journal of Physics* 62 (46), 1994.

[8] R.R. Hake, 'Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses', *American Journal of Physics*, 66 (64), 1998.

[9] J. Bernhard, 'Teaching engineering mechanics courses using active engagement methods' *Physics Teaching in Engineering Education*, 2000.

[10] P.C. Boylan-Ashraf, S.A. Freeman, M.C. Shelley, 'A Case for a Reform in Teaching Introductory, Fundamental Engineering Mechanics Courses', *121st ASEE Conference and Exposition*, Paper ID #9483, 2014.

[11] Z.J. Rohrbach, T.R. Buresh, and M.J. Madsen, ' Modeling the exit velocity of a compressed air cannon', *American Journal of Physics*, 80 (1), 2012.

[12] G.W. Parker, Projectile motion with air resistance quadratic in the speed, *American Journal of Physics*, 45 (7), 1977.

## Appendix

**Table 1.** Grading rubric for the project report.

| | **Unsatisfactory (less than 70 pts)** | **Developing (70 - 80)pts** | **Competent (80 - 90)pts** | **Exceptional (90-100)pts** |
|---|---|---|---|---|
| **Ability to apply kinetics to projectile motion** (*Q4*) | Demonstrates little or no knowledge of projectile equations or vector dynamics. | Possesses some knowledge of projectile equations and relative velocities. | Partially correct solution. May or may not use vector dynamics or relative velocity. | Correctly solved using vector dynamical equations, the location of broken pieces from launch point. |
| **Ability to conduct experiment and analyze data** (*Experiment + data tables + plots*) | Experiment was incorrectly conducted and tabulated data was incorrectly analyzed. | Less than half of the experiment was correctly conducted and tabulated data correctly analyzed. | At least half of the experiment was correctly conducted and tabulated data correctly analyzed. | Experiment was correctly conducted and tabulated data was correctly analyzed. |
| **Ability to formulate and solve engineering problems** [ *Eqn (1), Q3, modeling friction (f)*] | Failed to deal with velocity issues, failed to interpret 2000 ft/s flight of a projectile, major issues in the usage of either SI or US customary units, did not model friction at all. | Made a visible effort to overcome velocity issues, interpreted 2000 ft/s as the subsonic projectile flight, minor mistakes in using SI or US customary units, incorrectly modeled friction inside cannon. | Partially overcame velocity issues, interpreted 2000 ft/s as a subsonic flight of a projectile, used appropriate SI or US customary units, correctly modeled friction inside cannon. | Successfully overcame velocity issues, correctly interpreted 2000 ft/s as the supersonic flight of a projectile, used appropriate SI or US customary units, correctly modeled friction inside canon. |
| **Ability to apply math science and engineering principles** | Almost none of the above. | Some of the above. | Quite a few of the above. | All of the above. |
| **Ability to communicate effectively** (*Report*) | Key information is missing or difficult to find in figures; figures and tables are missing or totally ineffective. Report does not fulfill the needs of a reader. | Major clarity or conciseness, navigation issues. Figures, tables, conclusions unclear, wordy, or imprecise. | Minor clarity or conciseness, navigation issues. Figures, tables, conclusions could be more clear or succinct. | Excellent report formatting, organization, and style. Conveys key project information, figures and tables succinct |