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Mission-oriented Experiments for Year-one Physics Students

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Preamble

Year-one Physics students normally do experiments which illustrate the theory learned in lectures. For example, the falling of objects under the pull of gravity may be observed in so-called projectile experiments when a marble is thrown horizontally at some height. The marble finally hits the ground after traveling some range, much like a canon ball. Conventionally, students are asked to vary the height and measure the range in order to verify the law of projectile motion. This kind of measure-it assignments can be rather mechanical, so the student tends to "turn off his brain" while going through the routine in the lab. When he finally "uses his brain" to do the analysis at home, insights cannot be tested because he no longer has the apparatus.

Now imagine the experiment is done this way. The student is given a target on the floor. He has to adjust the height and speed of his "canon ball" to hit the target. With such a well-defined mission, all adjustments and measurements suddenly make sense, and the experimentation is anything but dull. The use of hands and brain in a feedback loop becomes a must, which is exactly what we hope to encourage. This report describes how we designed and implemented such mission-oriented experiments.

Abstract

Two new experiments, mechanical oscillations and kinetic theory of gas, were designed and implemented in undergraduate physics labs. A third experiment on heat transfer was also designed though not yet realised. Each of the three experiments carried missions that tested the fundamental concepts of the physics involved. The associated hardware and software were proven reliable and error-free. All experiments were executed through graphic-user-interfaces that featured standardised windows, much like playing games.

Keywords

Undergraduate physics experiments, mission-oriented experiments, game, mechanical oscillations, kinetic theory of gas, heat transfer

Introduction

Year-one Physics students are typically asked to verify known physical laws or operate sophisticated instruments in their lab assignments. The curiosity and problem-solving elements are usually absent. Compounded by recipe-like instructions, students tend to "turn off their brains" in the lab. And being devoid of the apparatus, they are forced to "turn off their hands" when writing reports at home. The experimental spirit, or the curiosity-driven problem solving by using the brain-hand feedback loop, is unfortunately missing. We tried to address the problem by introducing mission-oriented experiments a few years before. The essence was to ask students to fulfill well-defined missions in the lab that required good conceptual understanding and hand-brain collaboration. Encouraged by the positive results, this project aimed at introducing more experiments of this kind to cover the range of theoretical topics taught in year-one general Physics courses. Systematic evaluation of the pedagogical benefits was also undertaken.

Aims and Objectives

There were three objectives:

1. To design one or more mission-oriented experiments to cover
   - mechanical oscillations;
   - heat;
   - kinetic theory of gas; and
   - electromagnetic induction.
2. To have the experiments ready for students' use in the teaching lab.
3. To evaluate the pedagogical effectiveness of the experiments.

Methodology

The three objectives listed above were achieved in three stages, each called for different methodologies.

Experimental design stage

1. For each of the new experiments, the Principal Investigator first identified the key physics concepts to be learned. He then designed specific missions, and finally outlined the required hardware and software.

2. The Principal Investigator then presented his initial plans to the project team for criticism and revision. That typically involved three rounds of review.

3. Various members of the team then started assembling the apparatus, writing the software and doing test runs. The Principal Investigator was constantly involved in solving problems and giving suggestions throughout the process.

Getting experiments ready for the teaching lab:

1. After many rounds of revision, test runs and improvement, the setup and software were finalised.
2. The team then role-played to identify the key points that should be included in the lab manuals for students, and to finalise the graphic-user-interface and score tables. The Principal Investigator then wrote up the manuals.

Evaluating pedagogical effectiveness

In the second semester of the first year study, two out of the three new experiments, mechanical oscillations and kinetic theory of gas, were adopted for Experimental Physics II, a lab course for year-one Physics students.

The effectiveness of these mission-oriented experiments was evaluated in two ways:

1. Students were asked in a questionnaire to evaluate the usefulness of the game elements in the experiments.
2. Students were asked to do a multiple-choice quiz at the end of the mechanical oscillations experiment. Their quiz scores were compared against those in the previous year when game elements were not yet introduced. The quiz, set by another Physics faculty member, tested the key concepts of mechanical oscillation. Although the same quiz was used for the two years, its contents were neither disclosed to the Principal Investigator nor the students beforehand.

Results/Findings

There were two kinds of results:

1. the readiness of three new mission-oriented experiments; and
2. their pedagogical effectiveness.

New Experiments Ready. We had three new experiments ready: (a) mechanical oscillations, (b) heat transfer, and (c) kinetic theory of gas. The physical setups of the first two are shown in Figure 1. The third one is a computer simulation experiment requiring no apparatus other than the computer.

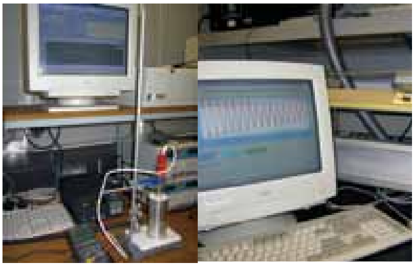

Figure 1. The experimental setups for heat transfer (left) and mechanical oscillation (right). Similar window design was adopted for all mission-oriented labs.

Instead of going into the technical details, we listed four general observations below.

1. Key physics concepts: In the process of designing the missions, the team debated and finally agreed on including just a few important concepts for each experiment. This focusing exercise was very beneficial in terms of sharpening the educational objectives. For example,

in Mechanical Oscillation, the student was asked to pick his combination of oscillator mass and spring stiffness in order to minimise the shaking effect of a vibrator.

2. Improvement of hardware: As students were required to produce quantitative results when they tried to fulfill the lab missions, the reliability, accuracy and consistency of the apparatus became more demanding than the conventional "measure and analyse" experiments. Much had gone into designing and improving the setups for the various mission experiments.

3. Software design: We aimed at giving students a uniform graphic-user-interface (GUI) for various experiments. For example, all GUIs comprised the following four windows: (a) student input, (b) experimental runs, (c) model answer and analysis, and (d) game scores. They were designed in such a way that students would be motivated to learn the correct approach (part c) once they saw how the actual empirical results (part b) deviated from their predictions (part a).

4. Game scores: Scores were computed in part (c) of the GUI. Again, much thought had gone into designing the score to reward sound concepts and careful experimentation yet without being discouraging. The team had repeatedly played the games themselves to guarantee the practicality.

Pedagogical Effectiveness. As explained in Methodology, students were asked to evaluate the game elements of the mission-oriented experiments. In particular, they were asked to compare the game experiments against conventional "measure and analyse" experiments under five headings:

1. Are they more interesting and exciting?
2. Do they help the students understand the physics concepts better?
3. Do they help the students' experimental skills?
4. Do they help the students integrate their analytical and hands-on skills?
5. Do they encourage team work?

The student response was summarised in Figure 2. The class size was 43. Two observations could be drawn. First, the responses were positive for all five categories. Second, it was considered the most effective in making the labs more interesting and exciting, as well as encouraging team work.

Again, as mentioned in Methodology, students were given a quiz immediately after the Mechanical Oscillation experiment. Quiz scores in the previous year (when game elements were not introduced) and the year in which game elements were included were compared in Figure 3. Full mark was 3 out of 3. The class which had game elements included in experiments did visibly better. Their average score was 3 points above the previous year, or about 10% higher.

Discussion

It is interesting to compare the students' evaluation of the new labs against our observations as lab instructors. As seen from Figure 2, the most apparent advantage of the new labs, according to the students, was the added motivation and excitement. This correlated well with our observations during lab time. Students were more punctual to labs, and were much more attentive and focused. We also found them better prepared. For example, they indicated that they had carefully read the lab manuals and were asking more questions.

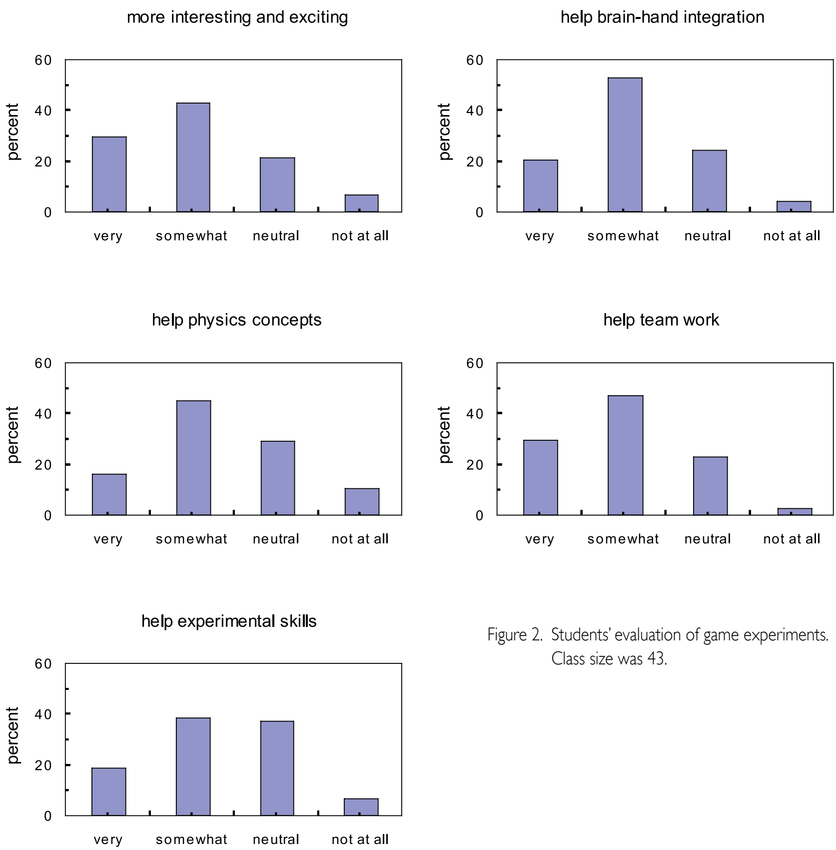

Figure 2. Students' evaluation of game experiments. Class size was 43.

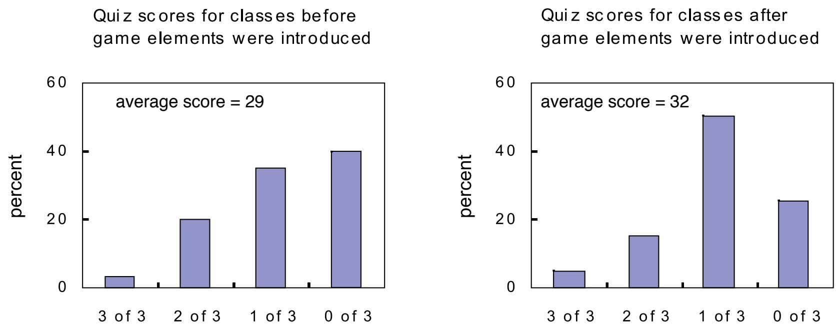

Figure 3. Mechanical oscillation quiz scores for classes with/without game elements included in experiments.

The next apparent advantage was that students thought it improved team work. This again was consistent with our observations. Now, we could see complementarities and synergism. Previously, it was more leader-follower mode or the simple work-partition mode.

The aiding of skills and brain-hand integration was not as apparent to the students. Although students were not aware of their improved ability to apply theory to solve practical problems, we as instructors felt that the improvement was real. For example, for the projectile experiment, if the current students were to enter into a competition on hitting the target, they would most probably have had scored higher than before because they would think about how to apply the theory of projectile motion to accurately deliver the marbles.

As for the final aspect of helping conceptual understanding, the students' impression of marginal gain seemed to agree with the findings shown in Figure 3, when the improvement in quiz results was only minimal. We attributed the small improvement to two reasons:

1. each lab mission could only focus on limited aspects of the many applications of a physics theory; and
2. the intense focusing on these narrow aspects, as required by playing a game, might box the student in.

As explained earlier, the quiz was set by another faculty member who did not know the lab contents while the quiz questions were not made known to the Principal Investigator. Under this kind of double-blind conditions, the marginal (10%) improvement in quiz results was already remarkable.

Enhancement on Teaching and Learning

As seen from the previous sections, the mission-oriented experiments enhanced teaching and learning in the following four ways:

1. By defining the mission of each lab assignment, it helped to sharpen the learning objectives. Again using the projectile experiment as an example, if students were asked to measure vertical versus longitudinal displacements, as in a conventional "measure and analyse" experiment, they would have had perceived this as an assignment without being aware of the "why". If they were to deliver the marble to the target, the motivation and the "why" would become clear.

2. They made the experiments more interesting and exciting, as perceived by the students and the instructors.

3. They helped the students to apply their theoretical knowledge to solve practical problems, an aspect that was not apparent to students though borne out in their game scores.

4. They helped the students to better learn some aspects of the physics theory but might not enhance their overall conceptual understanding. We will try to address this shortcoming in future lab design.

Limitations/Difficulties

We came across two technical difficulties:

1. We originally planned to use the Thomson jumping ring experiment to illustrate the concepts of electromagnetic induction. However, we came across technical difficulties that required a major redesign of the setup. We had to postpone the experiment.

2. As mentioned above, although the hardware and software were ready, we had to postpone the heat experiment because of lab scheduling. Evaluation of its teaching effectiveness had to be delayed.

Conclusion

Two new mission-oriented experiments: mechanical oscillations and kinetic theory of gas, were designed and used in the undergraduate physics lab. The game elements were favorably received by the students, and their performance in lab quiz was visibly better than that before game elements were introduced. A third experiment on heat transfer was also ready and will be used in class starting early next year.