Session 2480

# University Physics: A Hybrid Approach

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Abstract: The calculus-based introductory physics course serves a cross-section of majors but is mainly aimed at engineering students. Some of our recent experiences in applying new strategies in this course will be discussed. While addressing the Accreditation Board for Engineering and Technology (ABET) criteria in our course structuring, our methodology uses a hybrid combination of techniques including (1) project-based learning, (2) field trips, and (3) team-working tasks and group activities both inside and outside the classroom. The discussion in this paper includes content analysis of free-form written student responses, reports, and reflection statements, and how we can use these to modify the course and provide feedback to the students. We envision that these early experiences improve student attitudes and encourage more active and meaningful student participation in their own learning. Our experiences and lessons learned should be adaptable by a variety of engineering and science faculty in different course contexts.

## I. Introduction to our philosophy and methodology

There is a need to prepare students to face a variety of challenges, even those we as faculty cannot anticipate. Our courses must, therefore, not only provide the opportunity for students to learn the fundamental content knowledge behind today's science and technology, but also engage students in critical-thinking and problem-solving tasks in effective learning environments. We anticipate that the undergraduate curriculum can better prepare students for the demands of the 21st century workplace if we structure our courses in such a way that they exhibit the following seven traits:[1]

1. Encourage active learning
2. Communicate high expectations
3. Provide prompt feedback

4. Emphasize time on task
5. Encourage student-faculty interaction
6. Develop cooperation among students
7. Respect different learning styles.

For the past several years, we have been working with students, faculty and administrators to develop a calculus-based introductory course in physics that has these qualities. However, at the same time we do not wish to neglect the fact that engineering students need to demonstrate an acceptable level of understanding of the basic topics traditionally covered in such courses. A preliminary report of our successes and failures was published a couple of years ago,[2] and since then we have continued to modify and improve the course by listening to student feedback and using more efficient course structure and management, as well as through cross-college collaborations. Briefly, these changes have resulted in a course that better addresses the Accreditation Board for Engineering and Technology (ABET) criteria and gets students to take a more active role in their own learning.

There are many well documented methodologies for improving student learning of classical physics,[3-6] but even a quick review of the recent literature indicates that the discussion concerning what is the best teaching method or assessment tool is far from over.[7-12] We have been operating under the assumption that combining the best from all approaches, and tailoring these to fit the needs and situation of our own students, is the most effective way we can improve learning as well as student attitudes. We draw from many different techniques and ideas including those already cited and others,[13-18] and try to provide as many opportunities for students to learn as possible. The goal of this paper is to describe our experiences and lessons learned to help other faculty interested in modifying their courses do so in a cost-effective manner, as well as to demonstrate how a hybrid approach to active learning can be accomplished. We will describe the course structure briefly, followed by insights derived from student writings and feedback, some discussion of our lessons learned, and our overall recommendations for courses of this type.

## II. Course structure – Elementary Classical Physics I and II (Honors)

### II.A. Overview

The course we will be describing is a special section of our standard two-semester sequence of elementary classical physics. The Honors distinction implies it is for students in the university's Honors Program, however we also permit other students to enroll. This distinction allows us to teach the course differently and apply different performance standards for the students than for those in the other (normally two) lecture sections. Enrollment in the course has varied in the Fall term between about 35 and 50 students, with the latter being the most recent figure. In this case, we offered two back-to-back sections in order to maintain the interactive learning environment which is best offered in our case with classes of around 30 students. There is a very low drop out rate in Physics I – usually 2 or 3 students per semester and normally this occurs within the first week or so. Attrition from part I to part II is at about the 20% level, with most of this 20% opting to take a regular section of part II.

The "lecture" part of the course meets three times per week for 50 minutes each, and the "lab" component is flexible as we will describe below. We cover the same material in this course as is covered in the regular sections offered in our department. These are: Physics I – mechanics, kinematics, rotational motion, gravity, waves, static and dynamic fluids, conservation of energy, linear momentum and angular momentum (co-requisite of Calculus 1); Physics II – thermodynamics, electricity, magnetism, circuits, geometrical optics, physical optics (pre-requisite Physics I). Modern physics is a separate course in our curriculum. Our students are almost exclusively sophomore engineering majors, and we have a high percentage of female students (e.g., 16/50 this past term). The text we use is "University Physics" by Ronald Lane Reese (Brooks/Cole) which we reviewed for the community after our first experience using it.[19] This book differs from that used in the regular sections, which helps to make the distinction even more obvious to students.

## II.B. Goals

The goals we have set for our students for successful completion of this course are as follows:

1. Demonstrated ability to analyze equations and formulas, specifically identifying units and physical meaning of variables and the assumptions under which these formulas are valid.

2. Demonstrated ability to reason and articulate the physical behavior of systems based on dimensional analysis, symmetry arguments, proportional reasoning, and order of magnitude estimations.

3. Demonstrated ability to set-up and solve problems representing physical systems using variables without the use of calculators or numerical values.

4. Demonstrated ability to construct, interpret, and analyze graphs.

5. Demonstrated ability to analyze experimental data and formulate conclusions.

6. Demonstrated ability to design and build a working model involving some of the basic physical principles covered in the course.

7. Demonstrated ability to function and communicate well in group, team, and one-on-one environments, including written, visual, email, and oral communication.

8. Demonstrated ability to manage time and budgets.

9. Demonstrated ability to access resources for completion of projects, including literature and technical/professional/support personnel.

10. Demonstrated ability to connect physics and its learning to engineering, the other sciences, and society.

II.C. Assessment

Final grades for the course are derived from four sources, and are based on a straight scale with no curve: 93.0% and above = A; 90.0 – 92.9 = A-; 87.0 – 89.9 = B+, 83.0 - 86.9 = B, etc. The weighting of each component of the course is as follows:

1. (45%) Three equally-weighted tests taken by students individually. These tests occur about every 5 weeks, and no calculators, notes or books can be used. Students are given 60 minutes to provide solutions/explanations to six problems, all of which are equally-weighted. Students cannot invoke new variables other than those given in the problem statement, and most problems have about three parts on average. The instructor prepares and grades the tests, returning them usually the next class meeting and reviewing the solutions. The nature of the test questions and the rapid feedback provided by the instructor are important components of our approach. (Goals 1 – 4)

2. (15%) Homework. Homework problems are usually assigned and collected about once per week (eleven or twelve assignments per term), and are derived mainly from the problems section of the textbook and old exam questions (thus students rarely need a calculator for homework either). Students may work together on homework and turn in papers with multiple names, thereby sharing the score. Solution sets are provided by the instructor to the grader (a senior level physics major) which are transcribed and posted on the course web site.[20] Once in a while the instructor reviews some of the more difficult problems in class, and many hints and answers to questions are provided by email. The style and grading of homework is similar to that for the tests, and the graded papers are usually returned within one week. Solutions, however, are posted on the web site almost immediately after the assignments are collected to provide the most rapid feedback possible. Students are therefore encouraged to make photocopies of their homework solutions for comparison with those that are posted. (Goals 1 – 4, 7)

3. (15%) In-class participation. For more than half of the class meetings during the semester, students work in groups on conceptual problems from the textbook and on old exam questions. This represents 8 to 10 problems per week that the students work on in addition to homework. They know ahead of time what problems will be discussed and what days they will be working in groups. When students enter the room on these days they sit in randomized groups of 3 to 4 students. Randomization helps to build a learning community atmosphere and eliminates cliques. Each group is provided with a small whiteboard, pens and an eraser, and participation for that day is earned for those present without regard to whether students knew the material ahead of time. We encourage participation and rely on mutual peer-respect to motivate students to come to class

prepared. This approach is not fool-proof; sometimes it is obvious to the instructor that one student in a group is really not that well-prepared, but it is also obvious to the other group members (and as we often point out, nobody wants to be labeled as a "slacker"). We seldom see the same student repeatedly coming unprepared, and feel that the randomization of groups helps to keep the "pressure on". The instructor circulates throughout the class to each group (usually twice around) asking leading questions and verifying student understanding. Then each group presents their solutions to the entire class using their whiteboard and verbal explanations. The instructor raises questions and side issues during each presentation, and the class is encouraged to participate. The physical layout of the room allows for desks to be arranged in a "horseshoe" style to facilitate these interactions. (Goals 1 – 4, 7, 10)

4. (25%) "Lab".

A. Physics I:

The lab component of Physics I is a team project. Students are permitted to self organize into teams of four (our target number), but if they do not within the first two weeks of the course the instructor assigns team members. These assignments are based on written student responses to a questionnaire concerning when they have available times to work on the project as well as their areas of interest. The basic charge is to design and build a working model of a device that demonstrates concepts of physics such as energy and momentum. Students have the freedom to choose a project, which helps with the idea of ownership and at the same time avoids team competition since each project is different. At the first organized team meeting with the instructor, each team is given a logbook (carbon paper lab notebook). Logbooks serve as a record of each team meeting, a place to consistently organize ideas, research findings and contacts, as well as a convenient format through which the instructor provides written feedback on student progress throughout the term at intervals of about every two weeks. Teams are allocated a budget of approximately $400 (raised internally or from corporate sponsors) and are responsible for managing their own funds and reporting their expenses as part of the process. Purchases are either made by students locally for which they are reimbursed upon submission of receipts, or items are ordered by the instructor with his university purchasing card. Final presentations are made by each team to the entire class using video clips, PowerPoint slides and demonstrations during final exam week. The logbook as well as all presentation materials and the actual projects are submitted for final assessment. Free form reflection statements concerning the project and its meaning and usefulness to the students are also solicited but not required or graded. (Goals 6 – 9)

B. Physics II:

During the second term, students participate in what we call the lab, project, and field experience (LPFE) matrix (see Table 1). Actually the project work is essentially the team project from the first semester, and the second semester is occupied with tours of research facilities on-campus and at industrial sites, field trips to informal education locations such as science centers and the National Inventor's Hall of Fame (which happens to be here in

Akron), attendance at seminars, and performing several of our best in-house labs.[21] The matrix is based on the Accreditation Board for Engineering and Technology (ABET) criteria. For each activity that the students choose to do (we provide the opportunities with flexible times and days, and the students decide what to participate in), they submit a report describing the activity which is assessed based on the goals of the course. (Goals 4, 5, 7, 10)

5. E-mail. All students are required to use e-mail capable of opening MSWord documents to retrieve homework assignments, course announcements, and hints on the homework. Questions by e-mail are encouraged from the students, and this process saves many hours of the instructor's time as well as keeps all students informed in real time if they put forth the effort to actively check their email. Another benefit of using email is that anonymity is maintained; a question sent to the instructor is copied back to the entire class with an answer, but the student originating the question is not identified. In this way we hope to alleviate the apprehension that some students feel in asking questions, and also to demonstrate to the entire class that many students are struggling with the same concepts and problems. This may help to develop a learning community atmosphere, at least for those students that are not on campus often enough to participate in the study groups that some students self-organize. Regular office hours are maintained and the instructor has a completely open-door policy, and usually several students per semester choose to routinely use this option in addition to e-mail. (Goal 7)

6. Negotiation. This is an integral part of the course although it is not strictly part of the assessment. Negotiation provides students with the ability to have input into their learning and promotes an atmosphere of "buying in". Mutual respect between students and the instructor and amongst students themselves is fostered in this way. (Goals 7, 10)

## III. Student feedback and outcomes

We seldom have students failing this course, which is probably due in part to how we structure and run the course as well as to the pre-selection of students that are motivated (either by wanting to learn or by wanting to keep a good GPA) to participate fully. For example, averages from last term on the three tests are at about 76%, whereas homework and in-class work have averages of about 89% and 99%, respectively. Thus it is clear that the group work components of the class significantly helps students complete the course satisfactorily. In addition to the learning of content that occurs in these parts of the course, it is our opinion that students complete the sequence with a greater appreciation and enthusiasm for science and engineering. This is something we try to measure using course evaluations and other feedback instruments, some of which we discuss below.

Table 1. Lab, project, and field experience (LPFE) matrix

| | Projects | Seminars/ Colloquia | Labs | Reports | Field Trips | Research Facility Tours |
|---|---|---|---|---|---|---|
| Mathematics | | | | | | |
| Science | | | | | | |
| Engineering | | | | | | |
| Design and construct experiments | | | | | | |
| Design a system, component or process | | | | | | |
| Analyze and interpret data | | | | | | |
| Function on group design teams | | | | | | |
| Identify STEM problems | | | | | | |
| Formulate STEM problems | | | | | | |
| Solve STEM problems | | | | | | |
| Understand professional and ethical responsibilities | | | | | | |
| Communicate effectively | | | | | | |
| Be aware of STEM in a global/societal context | | | | | | |
| Engage in life-long learning | | | | | | |
| Know contemporary issues | | | | | | |
| Use modern STEM tools | | | | | | |

## III.A. Course evaluations

Over the past several years, we have used many different approaches to soliciting and using student feedback for improving this course. We find that overall, free form responses to broad calls for feedback provide significant amounts of information but that much of this is difficult to synthesize into specific areas of the course that need improvement. More focused questionnaires seem to be the most efficient method for assessing the views of the students. For example, our end-of-term anonymous course evaluation now contains more than fifty questions, organized to address different parts of the course (text, homework, classroom, project, exams, etc.). Figure 1 presents some of these results gathered from the most recent offering of part I of the course involving about fifty students. The questions are worded in such a way that a score of 4.0 is equivalent to a positive response such as "strongly agree" or in other words that the students grade that part of the course as an "A".

Specifically in Figure 1, the questions are that (1) the classroom was interactive, (2) the classroom was thought provoking, (3) the classroom encouraged student participation, (4) the classroom helped the student learn, (6) the project had commendable goals, (7) the project enabled students to practice real world skills, (8) the project provided more learning than normal labs, (9) the project took more time than normal labs. The error bars represent one standard deviation, and the number assigned to each question in the figure does not correspond to its location in the actual questionnaire but is simply for ease of presentation here.

There are several features of Figure 1 that are worth noting. First of all, the responses are very positive overall. Note that the three highest scores come from questions dealing with the structure of the course (1, 3 and 9), i.e. the course is interactive and takes time. This makes sense since there should be little doubt about the structure of the course - students feel it is interactive or not. We see the smallest error bars in these two cases as well. Students' opinions about whether they learned more than they would have in a normal course should be more variable. We see that the lowest scores come from how the students feel they learned (4 and 8), and that the error bars are the largest.

Whether a student feels they learned more depends a great deal on their attitude about the subject matter and what motivates them about learning in general. To gauge these responses, students answered the question "the same book should be used the next time this course is taught" with an average response of 2.54 and a standard deviation of 1.24. Thus we feel that our students are answering the questionnaire thoughtfully, in light of the fact that students are seldom in consensus about textbooks since they have no benchmark for comparison.

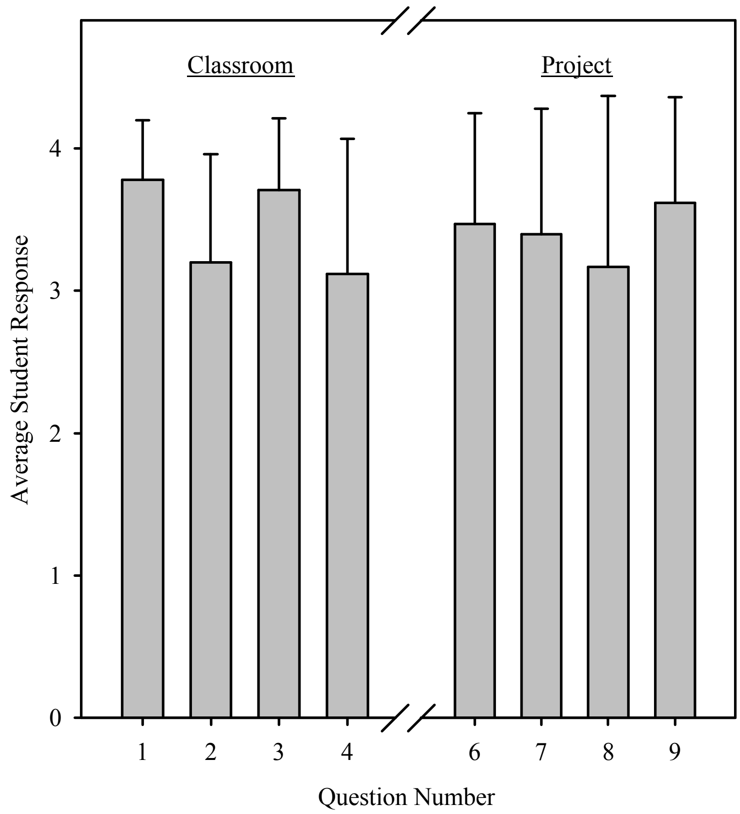


**Figure 1. Average of fifty student responses to questions on the anonymous course evaluation from last term (fifty one questions total). A score of 4.0 is equivalent to an "A" or "Strongly Agree", whereas a score of 0.0 is equivalent to an "F" or "Strongly Disagree". The questions are that (1) the classroom was interactive, (2) the classroom was thought provoking, (3) the classroom encouraged student participation, (4) the classroom helped the student learn, (6) the project had commendable goals, (7) the project enabled students to practice real world skills, (8) the project provided more learning than normal labs, (9) the project took more time than normal labs. Error bars represent one standard deviation.**

III.B. Survey responses concerning teaming during projects

The project part of our course is time-intensive for both students and instructor, but is very rewarding in many respects that makes it worthwhile in our opinion. As an example of what we mean by successful projects, Figure 2 includes photos of three devices constructed by students last term. The upper panel in Figure 2 is an electromagnetic rail gun (approximately one-half meter in length), which accelerates a small car from rest along a track. The three hand-wound coils along the acceleration tube are activated by discharging capacitor banks and triggered by photo-gates. The center panel is a remote controlled gasoline-powered seaplane with about a two-meter wing span. The bottom panel is a sling trebuchet that stands about four meters tall and can hold up to 300 lbs. of counter-weights. The main criteria for all projects are that they demonstrate physics in action, are safely constructed and tested, and that the team members can transport the project to the physics building once it is complete and have it fit through a standard doorway. Students are permitted to find prototype designs as a starting point, but then need to develop their own design criteria which they scale and modify to fit within the parameters (safety, cost, portability, etc.) of the project. Projects like the rail gun easily meet all these requirements since the device is small and portable and the acceleration of the test car is minimal.

**Figure 2. Some examples of the type and scale of projects that students work on. These rank in the top five out of thirteen projects completed in the Fall 2002 term.**

However, larger devices that fly (airplanes, blimps, hot-air balloons, etc.) or launch projectiles (ballistas, catapults, trebuchets, etc.) take more logistical planning. Teams that wish to build large or potentially dangerous projects are faced with obtaining permission from local authorities and our own health, safety, and risk assessment offices. Finding places to assemble and test these projects becomes a matter of networking and resource management for the teams. In addition, the physically large projects must be modular in design for quick assembly/disassembly to meet the portability requirements. For example, the trebuchet pictured in Figure 2 can be disassembled in less than six minutes and moved by the four-member team that constructed it. Students are given significant freedom in the project part of the course and with this the responsibility to self-regulate. They are very ingenious and creative in maximizing their use of personal and professional contacts in reaching successful completion and testing of their projects. The instructor serves a major role here in helping guide the direction that project teams follow, and after four terms we have had no major mishaps, complaints, injuries, or budgeting problems.

However, we are always looking to improve the learning that our students experience in all parts of the course, and the project component is no exception. Addition of the team logbooks two years ago has been beneficial, but our recent teaming with faculty in education and engineering has proven to be most important. As part of this collaborative effort, we are trying to identify more efficient ways of determining if our teams are functioning effectively throughout the term, thereby giving us a chance to intervene where needed. As an example, this past term the students provided short written answers to a four-part survey on team performance during the last week of October. Responses to "at this stage in the team project, evaluate the success of your team to function effectively" were content analyzed to provide the ordinate data of Figure 3. Student comments were ranked into low, medium, and high categories in the context of lower than, meeting, or exceeding expectations. Some examples of the type of categorization performed with the comments are:

Low - we are not effective; we are just bad planners; we are behind; we could work well is one of us took it seriously; some are looking for the easiest way to get a grade; our communication is poor;

Medium - we know exactly what we want to do but sometimes tasks do not get done; we get along well but sometimes don't accomplish what we assign; we work well together but I would feel better if we had more done; we are pretty good at communicating but not as effective as I would like; we want to succeed but can't agree on what to build; we are effective but it is hard to find time to meet;

High - we don't meet just to meet, we have goals; everyone gets their 2 cents in and we compromise; we are effective in making decisions and motivating each other; we are open to opinions and compromise; we contribute skills in a complementary way; we trust each other, rely and depend on each other; we waste little time; we have a high chance of success; everyone is doing excellent job; we are extremely efficient and effective, and are way before deadline.

Figure 3 demonstrates the usefulness of performing such a simple analysis of student comments during the middle of the term. There seems to be a trend that teams rating their own teaming abilities low during the term also end up receiving some of the lowest scores from the instructor. However, it is clear that even teams giving themselves a low self-rating recognize what qualities of a good team theirs is lacking. Another interesting piece of information is that eight of the students not taking part II of this course are from teams within the lowest six team-rankings. This would seem to indicate that teams that feel they are not doing well actually do not, and that they leave the course with less enthusiasm than those who are more successful. It is possible that data such as these comments, collected mid-stream during the term, could be used to highlight teams requiring more intervention and guidance by the instructor. As this was the first time this instrument was used, we deliberately did not use it for initiating intervention in order to see if it was a useful indicator of final team performance. Although team logbooks were monitored throughout the term, no specific indications of teaming behavior were evident like we find from this simple survey instrument. Seeing these results now, we definitely recommend using this or similar instruments as a way of determining where the instructor's time and effort is most needed.

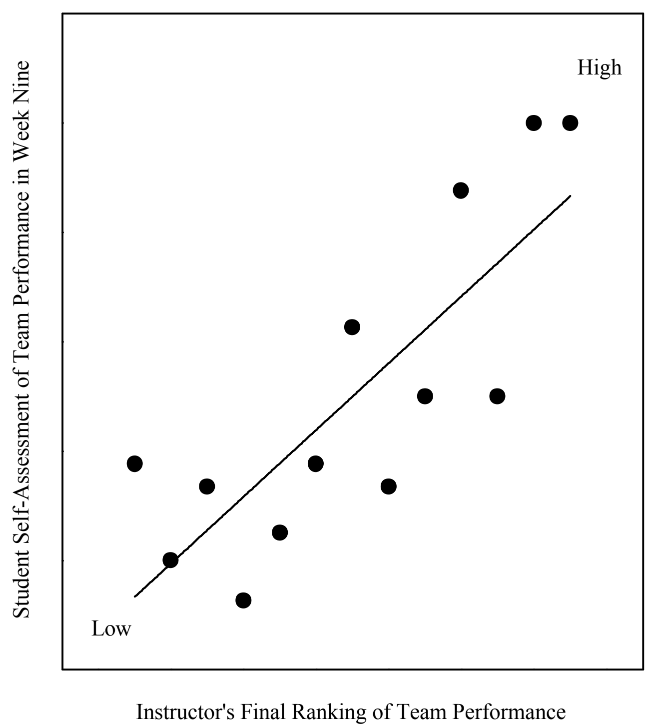


**Figure 3. Students answer the question "at this stage in the team project, evaluate the success of your team to function effectively" about two-thirds of the way through the semester, and the responses are content analyzed to obtain the ordinate data. The abscissa data is the instructor's final ranking of the teams based on all submitted materials and presentations. The questionnaire resulting in the ordinate data is not considered by the instructor in determining the final team ranking.**

III.C. Student self reporting in free form writings

In addition to surveys, written comments by students as they reflect on their own learning in free form reports can be a powerful tool in helping improve our courses. Figure 4 summarizes our content analysis of comments from the past two years. In the case of projects (LPFE activity A), reflection statements were analyzed and grouped into positive and negative responses. The large percentage of students providing these reflection statements (solicited but not required for the course grade) indicates that the project part of the course makes a significant impact on the students. Examples of the types of comments we receive are:

Positive - we learned far more than expected and what it takes to be a team; it was nice to take principles from class and apply them; it took a lot of work and dedication; having personal input into what we were going to work on was an advantage; we learned because we needed and wanted to not because we had to; we had the freedom to be inventive and creative and work together; we got a real sense of managing people and schedules; we learned networking; we learned to ask for help and built up confidence; the freedom and budget made for high expectations like we never had before; involves skills employers are looking for, elements of real world problems, and hands on experience;

Negative – it was a lot of work and I was not prepared; I don't like being graded on it; as long as it doesn't pull my grade down I have nothing negative to say; learning from mistakes is a good way to learn but not to earn a grade; all team members don't do their fair share so it is unfair they get the same grade; there are only a few physics principles involved in any project; we had problems communicating.

We combine this analysis of the projects with similar analyses of reports that students wrote for each of the other LPFE activities. In Figure 4, these are (B) seminars/colloquia, (C) field trips to informal education locations and (D) academic and industrial research facility tours. These reports were intended to convey to the reader what the student learned during each activity, however no direct evidence for self-reflection on one's own learning was required. Therefore, the data in Figure 4 indicate that students voluntarily self-reflect on learning less than one-fourth of the time after attending seminars but more than one-third of the time when participating in field trips and tours. Combining this with the percentage of these personal statements that were positive versus negative, Figure 4 would seem to indicate that seminars are the least effective of the four activities with regard to having students contemplate what they have learned. We feel that self-reflection statements indicate that students analyze information and put it into context, therefore demonstrating higher-level thinking in contrast to simply reporting the facts about what was seen and heard. The types of comments that we group together are:

Seminars/Positive - it was very informative; I could actually understand what she was saying; something I can now understand after studying these past chapters; it is important to stay up-to-date in contemporary issues; a common theme throughout these lectures is that answering one question leads to asking many more; it seems to me that to learn modern physics or quantum mechanics, one must almost unlearn many concepts we have been presented with for years; demonstrated how experiments can produce effects we never thought of;

Seminars/Negative - it was more confusing than informing; he made an assumption that we knew more than we did; too advanced for me to comprehend; well beyond my current level of ability.

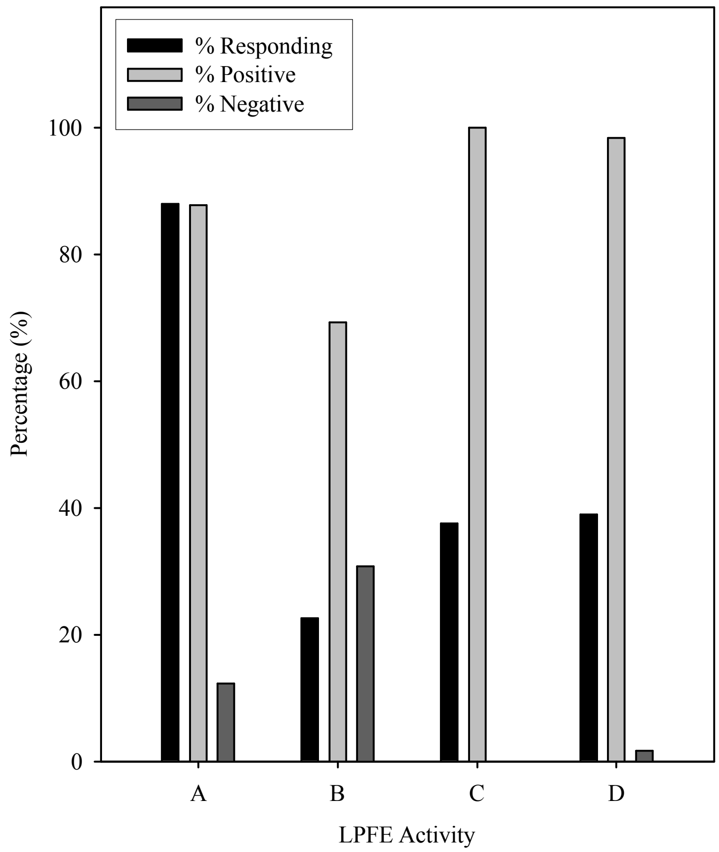


**Figure 4. Analysis of the percentage of students who included written personal statements concerning their own learning as part of the LPFE process, as well as the percentage of these comments that were positive and negative. The activities are (A) team project, (B) seminars/colloquia, (C) field trips, (D) research facility tours.**

Field Trips/Positive - very affirming to undergraduate engineering students who may have a tendency to lose perspective; I got to see some of the topics we are studying in class and how they relate to the real world; I would never have imagined how much politics plays a part; an inventor has to be aware of ethical responsibilities and have business skills; most of our education is geared toward the individual, yet most scientific work done in the field is done in teams; shows that science can be fun; it is remarkable to reflect on the ways I have learned over the years and how I am able to relate that to what I am learning now.

Facility Tours/Positive – it was surprising how a simple understanding of physics yielded a revolutionary breakthrough; I was actually quite amazed at some of the things I saw; it showed me how other subjects like chemistry and biology relate to physics; I am now considering doing some undergraduate research and experiments; this is why it is so important that the student of today be involved in learning how to work with others; shows that much research is a combination of several areas; I have a better sense of how physics is applied to research and development; I was impressed by the level of computerization; I learned about safety; it gave me insight into the business side of engineering; there was very loud testing and piping running everywhere; made me wish I had paid a little more attention in chemistry; they wanted to show us what they did which was really nice because it was authentic.

The only negative comments we receive about field trips and tours concern the difficulty that some students have finding time to participate, and the occasional missed tour due to poor driving directions or road conditions. Labs are not included in Figure 4 since we seldom see any unsolicited comments in the lab reports indicating that students reflect on their own learning during these activities. Even though we have spent several years developing a new sequence of in-house labs utilizing new equipment and computerized data acquisition, we are unable to show that students are learning at a deeper and more meaningful level. This is an area of concern that we will be addressing in the future.

## IV. Lessons learned

We summarize much of what we have learned in Table 2 for ease of reference. Although it is fairly well accepted that lecturing is not the best way for students to learn the material in introductory physics, we find that one day's lecture per chapter (or chapter overview as we call it) is worth doing. Our reasoning is two-fold: not only does this require low levels of effort, but it is comforting to students. Previous attempts to run the course without lectures resulted in negative feedback from students "not having notes" or "not knowing what to study". Lecture is what students are expecting, and we need to listen to their needs and wants as much as possible. We currently use these "lecture" times to actively engage students in a different way than when they work in groups, and it gives the instructor a place to convey the "big picture" view of the subject matter. In addition, it is a good way to let the students see how we as faculty think, what we find important, and to discuss ideas and questions that arise. So even though we would rate the learning as passive (abstract conceptualization) and the level of learning as low, we would rank the impact of lecture time on the students as medium – since we know what happens in its absence.

We find the in-class group work to be a definite plus, in that it allows the students to engage in peer-based learning that makes for a fun and interactive classroom. In addition, the students practice many more problems than we would hope to assign them for homework, and hone their presentation skills as well. For the instructor, this part of the course allows for meaningful interactions with the students engaged in problem solving. The most important key to making this part of the course work effectively is efficient use of class time. Students have to be convinced that it is in their own best interest to get to class on time and be ready to work. After working with this approach for several years, we routinely have entire classes that are set and ready to go before the class officially starts. Most of this success lies in the process of negotiation and the building of mutual respect within the class, and requires motivation, energy and enthusiasm on behalf of the instructor. Finally, it is necessary to have a room suitable for this type of classroom style, with moveable desks and plenty of space, and also small enough class sizes. We have managed forty students at a time in this style of learning environment, and use this value as our upper limit for enrollment.

**Table 2. Summary of our lessons learned***

| **Activity** | **Learning Mode** | **Learning Level** | **Student Effort Required** | **Faculty Effort Required** | **Resource Level Required** | **Impact Ranking** | **Number Analyzed^** |
|---|---|---|---|---|---|---|---|
| **Lecture** | AC | LOW | LOW | LOW | LOW | MEDIUM | N/A |
| **In-class Group Work** | AC/CE | MEDIUM | MEDIUM | MEDIUM | LOW | MEDIUM | N/A |
| **Projects** | CE | HIGH | HIGH | HIGH | HIGH | HIGH | 22 |
| **Seminars/ Colloquia** | AC | LOW | LOW | LOW | LOW | LOW | 115 |
| **Labs** | CE | MEDIUM | LOW | LOW | HIGH | MEDIUM | 118 |
| **Reports** | AC | LOW | LOW | LOW | LOW | LOW | 62 |
| **Field Trips** | AC/CE | MEDIUM | LOW | LOW | LOW | HIGH | 56 |
| **Research Facility Tours** | AC/CE | MEDIUM | MEDIUM | MEDIUM | LOW | HIGH | 157 |

*AC: Abstract Conceptualization; CE: Concrete Experience
^For this study

We strongly feel that the project part of this course is a unique experience for our students, and would highly recommend it for other courses as well. However, the effort and resources required are extensive, and planning and work by faculty before and after the term are essential. For example, our first year we did not use the portability requirement, and the instructor found himself with projects weighing over 400 lbs. that were too large to haul even in a standard pickup truck. Storing these in the physics building became impossible, and warehouse facilities are currently being used. We do not dispose of the projects, and have managed to display them at Spring commencement ceremonies and even at the National Inventor's Hall of Fame. This helps bring recognition to our students' achievements while at the same time fosters support for our continued offering of this section of the course. The infrastructure necessary for this involves staff and faculty from many areas, and good public relations goes a long way when it comes to needing project approvals and construction assistance. One thing that is important to realize is that too much of a good thing can be counter-productive, and we only do one large project per year with the same students – none of them have the energy or desire to do a second project in part II of the course.

We rank seminars and colloquia quite low in all areas in Table 2. We are considering either dropping or at least restructuring this component of the course. To date we have permitted students to attend essentially any science/engineering related seminar they choose. However, many speakers visiting The University of Akron are not expecting undergraduates to be in the audience and the students do not genuinely seem to learn much. In these cases their reports are more like transcribed notes that they jotted down during the talk, with little evidence that they are making connections or reflecting on having learned anything. There are exceptions to this of course, especially for speakers forewarned of the potential audience or those doing invited "after dinner" type seminars. Thus we are considering placing restrictions on the seminars that students can attend to those that we have had some hand in organizing. However, this would go against our philosophy of negotiation and providing opportunities and freedom to our students. Thus we are in somewhat of a "catch 22", and are working with our present students now to arrive at a mutually acceptable plan based on what we have learned from previous experience.

Labs traditionally offer students exposure to measurement techniques and data analysis, and deserve to be part of the physics curricular experience. We are quite surprised, however, that labs do not seem to impact student learning – at least with regard to their own personal self-reflections on learning (although we did not solicit these in particular). Perhaps the "lab report" is something that they are familiar with from other contexts, and that they have (unfortunately) learned by experience to keep their opinions and thoughts to themselves and focus on the facts. We will be working to alter this behavior, and are also trying some "take-home" labs. We hope that these will provide more flexibility for students' schedules (many of our students commute and have part-time jobs) as well as encourage the life-long learning concept of learning outside of the structured university environment. We need to be prudent in our use of such approaches, since, for example, our department justifies its M.S. graduate program essentially on the need for having teaching assistants in our undergraduate labs. However, we anticipate some added value to the students and are trying this in a preliminary fashion.

Reports are a separate column in the LPFE matrix (Table 1) to account for those reports that students submit that do not fit within the other categories. These mainly involve book reports and synopses of science articles and television shows. Table 2 shows that we rank these very low, and we have serious doubts as to their usefulness. We have tried making an assigned report based on "The Physics of Materials" booklet published by the

National Academy of Sciences[22] which had some benefit to students in our opinion. However, similar to the seminar component of the course, we are currently wrestling with how to allow student creativity while guaranteeing that learning actually occurs. Assessing the effectiveness of these non-traditional learning opportunities is difficult, and we find that cross-disciplinary collaborations are very helpful in this regard.

Field trips and research facility tours score very highly in our impact ranking, and we highly recommend this addition, even in limited form, to others developing new course structures and strategies. Students seem genuinely motivated by these experiences, and their reports reflect an awareness of their own sense of the scope and interplay of today's science and engineering disciplines. Off-campus tours take more time to organize since transportation and punctuality are essential. However, convincing the students that if they sign up for a tour with a local company they become representatives of the university seems to help, since we are putting our trust in them to be professional. This line of reasoning is especially effective for those companies that offer cooperative learning and potential employment opportunities to our students. Providing mileage and lunch reimbursement for longer trips has been possible to-date, and we intend to continue this as part of our efforts to expand this part of the LPFE (especially necessary if we minimize the role of the reports and seminars areas). For field trips we also buy admission tickets for students, and hope to continue this as well.

Several other portions of this course that may differ from other versions of elementary classical physics should be mentioned here. Our use of problems that do not involve numerical values is aimed at having students practice reasoning and analytical thinking instead of memorizing formulas and "plugging and chugging". We emphasize that it is not necessarily the final answer that is important, but the approach and content of the proposed solution or explanation. Students earn points for text as well as graphical or pictorial explanations, and very small "penalties" for minor mathematical errors are distributed (1 point out of 10, for example). Students are encouraged to solve/explain in whatever way is best for them, i.e., they do not necessarily have to solve problems in a certain format. Reference 20 may be useful to gauge the level and type of problems that we are discussing here. We admit that students are initially uncomfortable with this style of problems, since they normally focus on obtaining the final answer to problems that they know how to do in a certain way based on textbook and classroom examples. The open-ended nature of some of our problems makes students tentative and uneasy at the beginning of the course, and it takes constant encouragement to convince them that although this new type of problem is frustrating, it is worth their time and effort. Our basic argument is that we know that they can solve straightforward problems – that is how they got to be sophomores in college, and that employers do not want to hire employees who can solve numerical problems but instead want employees who can think.

Negotiation is the key to making all of this work, and building a sense of community and shared ownership. Learning students' names is a challenge but a necessary part of our approach. Listening to student needs and wants with regard to test and homework due dates, permissible LPFE projects and activities, etc. goes a long way to build the type of relationships within the class that we need in order to maintain and encourage performance. The major question is whether this approach will work for non-Honors type students? Our experience causes us to answer yes, since it is motivation and dedication that makes a student successful in this course. Do Honors level students always have these qualities? Not necessarily, since many of them did well in high school through the use of memorization and "playing the game". Such students are often hesitant to take the challenge that our course offers, since their Honors ranking and associated scholarships depend on GPA alone and they know that they can "get an A" in a course structured "the normal way". However, we would argue that given the opportunity, many students have the ability to excel in the type of environment that we create through this course. This is why we permit non-Honors students to enroll, and we have not been disappointed.

## V. Summary

We hope that this paper gives the reader some indication of the types of activities that we are providing for our students in introductory physics, and just how creative and motivated some students can be. However, most importantly, we hope to raise questions and provide some guidance based on our lessons learned to others in the community that are wrestling with making changes in course offerings in response to pressure from a variety of sources. We feel that we (and our students) have met these new challenges head-on, and have made significant progress at making our course more interactive and meaningful for students without compromising the learning of content knowledge. Actually, as we have grown more accustomed to the style of the course, we find it to be an enjoyable and rewarding use of our time because of the constant challenge to keep up with students' ideas and questions. We hope that others will build on what we have learned and realize that no one style of learning fits all students. This is why we are strong advocates for a hybrid approach to learning physics.

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