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A Learner-Centered Approach for Preparing At-Risk Students

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AC 2008-1983: A LEARNER-CENTERED APPROACH FOR PREPARING AT-RISK STUDENTS

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A Learner-Centered Approach for Preparing At-Risk Students for Success in Engineering

I. INTRODUCTION

The Picker Engineering Program, established in 2000, is the first engineering program at an all-women's college in the United States. One of its aims is to develop learner-centered pedagogies that better attract, educate and retain women in engineering. In their first year at Smith, prospective engineering majors take calculus, physics, chemistry, and computer science, as well as a project-based introduction to engineering. The first engineering course with rigorous scientific content is EGR 270, Continuum Mechanics, which students take in the fall of their sophomore year. Since the program's inception we have found that a number of students struggle in this course because of difficulties with pre-calculus math skills, calculus and physics.

This paper presents the rationale, content, pedagogy and assessment of a one-week course designed to help academically at-risk engineering students in the summer before their sophomore year. The primary goal of the course, Physics and Engineering Problem Solving, is to deepen conceptual understanding and to improve problem-solving skills for selected topics in physics and engineering. A secondary goal is to facilitate the development of a relationship between the participants and Smith's Quantitative Learning Center (QLC). To achieve these goals, the course was developed using learner-centered strategies that are based upon both cognitive and social cognitive theories about learning.

In cognitive theory, learners are seen as constantly building a mental representation or cognitive structure that models their world. This theory suggests that a lecture approach to teaching is not likely to encourage meaningful learning in any but the most highly motivated learners. It also suggests that learning proceeds better when students have a conception of the learning outcomes they are seeking and employ metacognitive skills of self-monitoring and self-regulation to achieve them. To develop these learning outcomes for Physics and Engineering Problem Solving, physics and engineering faculty worked together to identify key content and skills necessary for success in EGR 270 and the engineering program in general. These intended learning outcomes are discussed in Section II and presented in detail in Appendix A. They include understanding motion graphs; plotting integrals and derivatives of a function; improving algebra and trigonometry skills; applying problem-solving strategies including units and limits evaluation; drawing and applying free-body diagrams; and developing a better conceptual understanding of integration and the skills to apply it.

Social cognitive theory suggests that engagement often happens in a context in which students encounter the thinking of others. In this view, learners construct knowledge only after they encounter and use the knowledge in a social context and with the help of scaffolding provided by more knowledgeable individuals. Providing a supportive collaborative environment for this to occur may be particularly critical to the success of women—who are underrepresented and particularly at risk in the engineering classroom. In their study of thousands of women engineering students from 53 institutions, Goodman et al.[1] found that women leaving engineering programs often cited dissatisfaction with teaching, workload and pace, as well concerns with the program climate—including competitive, unsupportive and discouraging faculty and peers. They summarize the concern of engineering education reformers as follows: "…the interests, socialization, and experiences of women (and other underrepresented groups) are often at odds with traditional engineering structures. These populations tend to flourish, on the other hand, in settings that emphasize hands-on, contextual, and cooperative learning." Thus in Physics and Engineering Problem Solving, an emphasis was placed upon creating a positive social context that supported collaboration, shared thinking, and risk taking, and that facilitated various kinds of engagement with the content in ways likely to build understanding.

Physics and Engineering Problem Solving was offered for the first time in the summer of 2007. Students were invited to attend the course if they received a grade of C+ or below in PHY 117 (Advanced General Physics I) or had taken PHY 115 (General Physics I—a less mathematically advanced version of PHY 117 that covers the same content). Based upon this criterion, twelve students were invited to participate in the course. All decided to participate; however, one student could only be present for two days and is therefore not included in the course assessments. In future years we expect to make the course mandatory for students identified by the above criteria.

II. IN THE CLASSROOM

The class met for six hours a day for five consecutive days during the last week of August. All 11 students attended each session and arrived on time and were actively engaged throughout the entire class time. Prof. Glenn Ellis from the Picker Engineering Program was the lead instructor in the course. Dr. Catherine McCune, Director of the Quantitative Learner Center (QLC), also led a two-hour session and was present for much of the class time. Two Smith engineering students—Shannon Comiskey (a junior) and Briana Tomboulian (a senior)—provided additional assistance in the classroom. Hands-on activities and laboratories, group-learning experiences and class discussion were the primary pedagogies used in the class. Care was taken to address a variety of learning styles for each topic.

Day 1 – Plotting

The intended learning outcomes for Day 1 focused on understanding and quantitatively plotting position vs. time and velocity vs. time graphs for a given motion and plotting the integral and derivative of a graph.

Activities:

- The course started with an introduction of the participants, pedagogy and content. This included framing the class in terms of bringing together a community of learners who share cognitive responsibility and in which each member feels safe to make mistakes and ask questions. Students were also encouraged to focus on identifying their own learning needs during the course and to work at their own pace within the course framework to address these needs. The role of formative assessment for helping them identify these needs and monitor their progress was also discussed.
- Students completed a content-based pre-assessment (see Appendix B).

- Students worked on developing an intuitive understanding of position-time and velocity-time graphs and the derivative/integral relationship between them by completing an extensive series of kinesthetic activities. In these activities students used Vernier motion detectors[2] to measure and plot their position or velocity in real time as they walked to match different motion graphs or descriptions of motion. (Details of these activities are given in Ellis and Turner[3].)
- Students practiced plotting motion graphs from motion descriptions (and vice-versa) and plotting integrals and derivatives of functions.
- Peer teaching was used as student teams took turns demonstrating and explaining complicated position-time and velocity-time graphs to the rest of the class.

Day 2 – Problem-Solving Methods (units, limits, framework) and Algebra
The intended learning outcomes for Day 2 focused on problem-solving approaches, evaluating solutions and units, and solving single and simultaneous equations.

Activities:
- Students decided to spend part of the day finishing plotting activities from Day 1.
- Students participated in an interactive lecture and problem-solving session led by the QLC director that focused on algebra and solving equations.
- The Expert Problem Solving Framework (see Appendix D) was discussed within the context of the expert-novice research on learning. The skills needed to check units and evaluate answers were particularly stressed and students practiced them in a variety of activities. For example, in one activity students were given engineering exam questions and checked sample answers by evaluating the units and limits of the answer. The instructor continued to model the framework by using it to evaluate answers throughout the week.

Day 3 – Newton's Laws
The intended learning outcomes for Day 3 focused on understanding Newton's Laws, drawing free-body diagrams and solving one-dimensional dynamics problems.

Activities:
- Students completed a discussion-activity session on Newton's Laws that focused on improving conceptual understanding and the ability to draw free-body diagrams. The prompts for the discussions included activities in which students explained Newton's Laws to each other in their own words, answered numerous concept questions, and applied procedures for identifying Newton Third Law force pairs and drawing free-body diagrams. Several kinesthetic activities were included. In one, students explained the forces they felt on their feet while jumping and then used Vernier force plates[4] to plot these forces in real-time.
- Students learned about how dynamics concepts fit together through exploring and applying a dynamics concept map that illustrated how Newton's Laws related motion to its causes (see Appendix E).
- Students completed a discussion-activity session that focused on addressing misconceptions related to friction forces. Concept questions and kinesthetic activities—such as examining the friction forces felt while walking and running—were used to direct discussion.

- Students worked in teams to solve dynamics exam problems from PHY 117. As the instructor and student assistants noticed common misconceptions, they were addressed in short class discussions.
- Students toured the QLC and participated in a question and answer session with its director.
- The final activity of the day examined the dynamics of an elevator ride. Students began by drawing free-body diagrams of themselves riding an elevator and shared their predictions with their lab partners. They tested their predictions by riding an elevator while standing on a Vernier force plate that produced real-time graphs of their apparent weight.

Day 4 – Trigonometry
The intended learning outcomes for Day 4 focused on applying trigonometry to find vector components and solve two-dimensional dynamics problems.

Activities:
- Students decided to continue working on solving dynamics problems started in Day 3.
- Basic trigonometry concepts were reviewed and applied in the context of solving mechanics problems.
- Students worked on two-dimensional dynamics problems that integrated most of the content covered during the week. This provided an opportunity for students to evaluate their learning needs and receive extensive individualized help.
- Students ended the day with a social event—going out for ice cream as a class.

Day 5 – Integration
The intended learning outcomes for Day 5 focused on conceptual understanding of a differential element and finding masses and centroids using integration.

Activities:
- A short lecture, discussion and example problems were used to improve student conceptual understanding of differential elements and how they are used in performing integration. Students applied this knowledge by working individually or in groups to determine the masses of areas with non-constant density and also the centroids of areas.
- Students completed a content-based post-assessment (see Appendix C).
- Students participated in a class discussion focusing on strategies for learning and for success in their classes.
- Students met with the course instructor and the director of the QLC to review their progress on the content-based assessments and to articulate their academic goals. Based upon this information, strategies and content to be focused upon in the coming semester were discussed and most students scheduled a meeting with the QLC director for the first week of classes.

III. RESEARCH METHODOLOGY

At the beginning and end of the course students completed content-based assessments designed to measure their progress in achieving the intended learning outcomes. At the end of the course students also completed a brief self-assessment survey to gather information in three categories:

pedagogical methods, confidence levels, and interest in continuing in engineering. Finally, the grades of students who subsequently participated in EGR 270 and the attendance of class participants at the QLC were examined.

Participants

Eleven students participated in the week-long seminar. All participants were pre-engineering majors and had previously taken a physics course in which they received a grade of C+ or below. Participation in the class was voluntary and required that they return to campus a week before the general student population. Participants were all sophomores and were from diverse ethnic backgrounds, including Asian, African-American, Hispanic, Caucasian, and multiracial.

Data Collection and Analysis

Assessment of Intended Learning Outcomes

Students were assessed for content understanding related to the intended learning outcomes at the beginning and end of the course using two similar one-hour assessments consisting of 12 questions. The pre-assessment tool is provided in Appendix B. The student solutions for each question were marked as being correct, having minor errors or having major errors. The results are shown in Table 1. This table shows that students entered the course with adequate skills in solving basic single and simultaneous equations, as well as solving basic problems in trigonometry. Because of the pre-assessment results, less time than originally scheduled was allocated to these subject areas and only minor improvements were measured in the post-assessment. The one exception was the significant increase in student performance in applying trigonometry to solve two-dimensional dynamics problems.

Many students entered the course with inadequate knowledge and skills in the following areas: drawing graphs of the integral and derivative of a function, drawing free-body diagrams and applying Newton's laws of motion, and integration. The deficiency in integration was particularly notable in that no student in the class was able to make any progress in calculating the mass of a triangle with varying density while completing the pre-assessment. (Although the assessment stated that they should only attempt the integration problem if they had time, it should be noted that all of the students handed in the assessment with time to spare.) All of these content areas showed large improvements in the post-assessment. Pre-and post-assessment results are shown in Table 2.

Intended Learning Outcome Assessed	Pre-Assessment Solution			Post-Assessment Solution		
	Major Errors	**Minor Errors**	**Correct**	**Major Errors**	**Minor Errors**	**Correct**
Given a description of the motion of an object in one dimension, plot position vs. time and velocity vs. time.	0	7	**4**	0	1	**10**
Given a plot of position or velocity vs. time for an object in one dimension, generate the other plot (velocity or position).	6	4	**1**	1	1	**9**
Given a plot of position or velocity vs. time for more than one object in one dimension, give a clear, English description of the motion.	1	5	**5**	0	2	**9**
Solve an equation for a variable (whether the other terms are numbers, other variables, or both).	0	1	**10**	0	0	**11**
Solve simultaneous equations for a specified variable, eliminating one (or more) other specified variables.	1	2	**8**	0	3	**8**
Given a formula, analyze its units and check if they are correct.	2	4	**5**	0	0	**11**
Given a description in words of an object with forces on it in 1D, draw a free-body diagram… This includes identifying third law pairs.	8	1	**2**	0	6	**5**
Given a description in words of multiple objects with forces on them in 1D, draw a free-body diagram.	9	1	**1**	0	4	**7**
Given some angles and/or sides of a triangle, find other angles, sides, and trigonometry functions using the Pythagorean theorem and SOHCAHTOA.	2	1	**8**	0	0	**11**
Given a figure with angles labeled in one or more places, figure out what other angles in the figure must be equal to the given ones.	0	1	**10**	0	1	**10**
Given a description in words of an object with forces on it in 2D, draw a free-body diagram… Break a vector into components along tilted axes.	3	5	**3**	0	5	**6**
Find the mass of a figure by integration.	11	0	**0**	2	3	**6**

Table 1: Pre- and post-assessment of intended learning outcomes (based on 11 students attending the class).

Self-Assessment Survey

In order to gather information about student perceptions and reactions after taking the class, Dr. Mary Moriarty, Assessment Researcher for the Picker Engineering Program, administered a brief self-assessment survey. The survey consisted of 15 numeric and three open-ended questions. All 11 students filled out the survey on the last day of class. The results are reported in Table 2.

An analysis of the results showed a positive response in all categories. Several questions were designed to elicit information regarding the pedagogical methods, i.e. learner-centered approach, incorporating teamwork and the use of multiple methods for students to engage in the learning process. The student responses to the teaching methods were overwhelmingly positive. Ninety-one percent of the students agreed or strongly agreed that both the methods used to teach the class and working in teams was helpful to them. They (91%) also reported that walking the plots (a kinesthetic learning method) and using motion detectors (a hands-on learning activity) helped them to better understand position-time and velocity-time graphs. One hundred percent of the students agreed or strongly agreed that they now understood these concepts on a deeper level.

Student responses to questions regarding their confidence levels after taking the class were also favorable. This is important because research has shown that the retention of women in engineering is related to confidence levels.[5] Eighty-three percent of the students agreed or strongly agreed that they were more confident of their physics abilities, 100% reported that they were more confident of their mathematical abilities, and notably, 100% of the students reported they were more confident of their ability to succeed in engineering. Student responses to open-ended questions also confirmed an increase in confidence. For example, one student reported that she was surprised she had learned and understood the concepts of Newton's Laws now. She indicated that, previously, it was something she didn't want to attempt, but now she was more confident. Another student reported that she learned "calculus stuff" that—even though she had done it in physics – had never made sense to her. She echoed the responses of her fellow students and indicated that she now feels more confident about integration.

In addition to feeling more confident, students indicated that the course had a positive impact on their desire to continue in engineering. Ninety-one percent of the students agreed or strongly agreed that they were now more likely to take additional engineering classes, with only one student remaining undecided. Students (73%) also indicated that they developed learning strategies that would help them in other classes and 100% now felt more a part of a learning community. Overall, students had a very positive response to all aspects of the class. They reported that the class was fun and interesting, that the professor and teaching assistants were helpful, and that they liked moving around and "testing" their theories.

Variables	Frequencies					Mean
	SD	**D**	**U**	**A**	**SA**	
1. The methods used to teach this course were helpful to me.	0	0	1	**1**	**9**	4.73
2. Walking the plots helped me to better understand the concepts being taught.	0	1	0	**3**	**7**	4.45
3. I feel that I am more a part of a learning community.	0	0	0	**4**	**7**	4.64
4. Working in teams was helpful to me.	0	0	1	**3**	**7**	4.55
5. I feel more confident in my ability to succeed in engineering.	0	0	0	**4**	**7**	4.64
6. I am more likely to seek out help from the Quantitative Learning Center.	0	0	0	**5**	**6**	4.55
7. The use of the motion detector helped me to better understand position-time and velocity-time graphs.	0	0	1	**4**	**6**	4.45
8. I am more likely to take additional engineering classes.	0	0	1	**4**	**6**	4.45
9. I now understand plotting of position-time and velocity-time at a deeper level than I previously did.	0	0	0	**3**	**8**	4.73
10. I am more confident in my mathematical abilities.	0	0	0	**4**	**7**	4.64
11. I am more confident in my physics abilities.	0	0	2	**4**	**5**	4.27
12. I developed some learning strategies that will help me in other classes.	0	0	3	**1**	**7**	4.36
13. I wish that I had taken this class sooner.	0	0	0	**2**	**9**	4.82
14. I understand the importance of learning from mistakes.	0	0	0	**4**	**7**	4.64
15. I now understand Newton's laws at a deeper level than I previously did.	0	0	2	**3**	**6**	4.36
16. I learned more than I expected in this class.	0	0	0	**1**	**10**	4.91

Table 2: Variables by frequency and mean, (based on a scale of 1 to 5; SD=Strongly Disagree, SA=Strongly Agree)

Post-Course Follow-up

Early data from the Fall 2007 semester indicates that the gains associated with the Physics and Engineering Problem Solving class may have resulted in only modest long-term gains in other classes. Nine of the 11 students (including two who planned to quit engineering before taking the summer class) decided to enroll in the next-level core engineering class (EGR 270 Continuum Mechanics) and achieved moderate success. One student received a grade of B, five students received a C, and three received a D grade for the semester. It is not known whether students would have received lower grades had they not participated in the summer class or how students have progressed in their other courses. At this time grades are not available for other courses taken and no data is available regarding student perceptions about learning/teaching methods used in EGR 270. An examination of records from the Quantitative Learning Center indicates that only two of the nine students sought academic assistance despite previously indicating that they were likely to do so. In addition, tutorial visits for the each of the nine students were limited to just a few. The reasons for this lack of participation are not known and additional research will be conducted to gain a better understanding of academic progression, participation in support services, and student perception. It should also be noted that records are not kept for meetings with tutors assigned to specific courses (as contrasted to the tutors addressing more general individualized needs in the QLC), so any follow-up with these tutors was not measured.

IV. DISCUSSION

Drawing upon a broad research base, the National Research Council (NRC) recently reported the following points as key to successful learning[6].

1. Students come to the classroom with preconceptions about how the world works. If their initial understanding is not engaged, they won't change or they may learn for the test and revert to preconceptions.
2. To develop competence in an area, students must (a) have a deep foundation of factual knowledge, (b) understand facts and ideas in the context of a conceptual framework, and (c) organize knowledge in ways that facilitate retrieval and applications.
3. A metacognitive approach [involving the learners' knowledge of their own thought process] to instruction can help students learn to take control of their own learning by defining learning goals and monitoring their progress in achieving them.

We will use these points as a framework to discuss the approach to teaching and learning that took place in the course.

1. The NRC writes that instruction can be viewed as "helping the students unravel individual strands of belief, label them, and then weave them into a fabric of more complete understanding." This requires designing classroom experiences and formative assessments that help "make students' thinking visible to themselves, their peers, and their teacher."[6]

In Physics and Engineering Problem Solving, this was accomplished through (1) a variety of kinesthetic activities exploring dynamics concepts, (2) concept questions designed to reveal common misconceptions, (3) questions requiring students to write or verbalize their understanding of concepts in their own words, (4) laboratories that involved making predictions about physical behavior, and (5) the content-based assessments at the beginning and end of the course. In many of the kinesthetic activities students were able to discover and address their misconceptions themselves. For example, students trying to walk a motion that matched a given position-time graph saw in real-time if their movement was successful. If it was not, the lab group would discuss the discrepancies and revise their walking motion until they were successful. In many of the other activities the instructor was needed to provide feedback and to lead impromptu discussions, demonstrations or activities that addressed the identified misconception.

As presented earlier, student responses to these methods were very positive. It is interesting to note that there were no negative student responses (either informally expressed to the teaching team or formally through the post-course surveys) to the content-based assessments. This may have been due in part to making the role of formative assessment in the learning process explicit throughout the course. Many students did express satisfaction in seeing how much they learned during the week when they compared their pre- and post-assessment performances; this may have been a factor in the measured increases in confidence.

2. From the research that compares the performances of experts and novices, we know that experts approach problem solving and organize their knowledge in very different ways from novices. For example, when asked to describe their approach to solving physics problems, experts tend to mention major principles or laws that are applicable and the rationale of why and how they can be applied. By contrast, novices typically refer to equations and how they can be manipulated.[6,7,8] The NRC writes:

> Experts' thinking seems to be organized around big ideas in physics, while novices tend to perceive problem solving in physics as memorizing, recalling, and manipulating equations to get answers. When solving problems, experts in physics often pause to draw a simple qualitative diagram—they do not simply attempt to plug numbers into a formula…Experts appear to possess an efficient organization of knowledge with meaningful relations among related elements clustered into related units that are governed by underlying concepts and principles.[6]

To address the expert/novice research, two pedagogical tools were used in the course to help students take an expert approach to problem solving and to organize their knowledge in meaningful ways. The first tool is the Expert Problem Solving Framework (see Appendix D). In this framework, an expert approach to problem solving is broken down into steps in a way that can be understood and applied by the students. Using this framework, students first draw a picture that translates the problem statement into specific variables. Students then identify key ideas or principles that apply and solve the resulting equations. Finally, they evaluate their answer and check the units of their answer. The students were first introduced to this framework in PHY 117. The framework was reintroduced to the Physics and Engineering Problem Solving students in the context of a discussion of expert/novice research. While the entire framework was modeled by the instructor and used by the students throughout the week (much to the surprise of the students who noted that they rarely saw such clear connections across courses and instructors), the focus was initially on evaluation and unit analysis. In one activity, students were given problems and possible answers from engineering courses that the students were to take in their future. They evaluated the answers by finding how the answers changed as the variables in the problem were taken to their limits. In the same problems, they also simplified units in complex answers to see if they were consistent and reasonable. Students were highly engaged in this activity and the expert/novice discussion. It appeared that learning about how to become an expert and practicing evaluating answers of future courses may have had an empowering effect and contributed to their increased confidence.

The Dynamics Conceptual Framework (see Appendix D) was the second tool used to help students develop an expert's competence. This framework illustrates the interconnections among free-body diagrams, Newton's Laws and motion graphs. Similar to a concept map, its purpose is to help make issues of knowledge, knowledge structure, and the way ideas are related more explicit to students. It was used to organize the dynamics concepts explored in the class and also as an aid in problem solving by helping students identify solution pathways. A detailed discussion of the framework and its application in the classroom are given in Ellis and Turner[9] and Ellis et al.[10]

3. Theory directs us to believe that the best way to teach metacognitive strategies is to first model their use explicitly and then, in a variety of ways, encourage students to internalize the strategies. In Physics and Engineering Problem Solving, the pedagogies used in the classroom were discussed regularly and the purpose of each activity in the learning process was made explicit. Students were often asked to focus not only on what they were learning, but also to think about what they wanted or needed to learn, how they were going to monitor their progress and how they planned to achieve their goals. Consistent with the need for students to take greater responsibility for their learning, a variety of decisions regarding the content and pace of the course were made by the students in the class. For example, students decided to slow down the pace on Days 2 and 4 to spend more time on graphing and dynamics, but decided to increase the pace at the end of the course to allow time to study integration. It is also noteworthy that many in the class identified that their learning need was to better understand integration at the conceptual level. Within the framework of each day, students made decisions regarding the pace and focus of their own learning, and the activities pursued in the afternoon of Day 4 were totally up to the student. Finally, the student meeting with the QLC director and course instructor on Day 5 focused on helping students start to take control of their learning based upon the content-based assessments.

Although the class was successful by a number of measures, the long-term impact of the intervention remains unclear and merits further research. Undoubtedly a single week is insufficient in scope to provide the level of support required by many academically at-risk students. Thus the authors support the development of a more extensive system of monitoring, intervention and support for students. This system should start at the earliest possible time in a student's education. The need for earlier interventions is also supported by our assessment data: all of the students indicated that they wished they had taken the course earlier. Based upon the positive response to the course presented in this paper, we also strongly recommend that these interventions be learner-centered and based upon the research on learning.

V. CONCLUSIONS

A one-week course designed to help academically at-risk rising engineering sophomores in the areas of physics and mathematics was created and assessed. A learner-centered approach based upon both cognitive and social cognitive theories was shown to be effective in terms of achieving the intended learning outcomes developed for the course. These included an improved understanding of motion graphs, plotting integrals and derivatives of a function, algebra and trigonometry skills, problem-solving strategies including units and limits evaluation, drawing and applying free-body diagrams, and understanding integration and its application. A student self-assessment also supported that the methods used in the course—including kinesthetic learning with motion detectors, hands-on applications, emphasizing conceptual understanding and framing knowledge, group problem solving, and individual tutoring—were all effective. The self-assessment indicated raised student confidence levels and a desire to continue in engineering. In spite of these short-term successes, the long-term student impact remains unclear and will be addressed through further study and interviews of the students in the class.

VI. ACKNOWLEDGEMENT

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APPENDIX A: Intended Learning Outcome for Physics and Engineering Problem Solving

Day 1 – Plotting

1. Given a description of the motion of an object in one dimension, plot position vs. time and velocity vs. time.
2. Given a plot of position or velocity vs. time for an object in one dimension, give a clear, English description of the motion, including:
    a. When is it moving or standing still?
    b. In what direction is it moving at different times?
    c. Comparing two times, when is it moving faster or slower?
3. Given a plot of position or velocity vs. time for more than one object in one dimension, give a clear, English description of the motion, including:
    a. When is one object ahead of the other?
    b. When do they pass each other?
    c. When is one object moving faster than the other?
4. Given a plot of position or velocity vs. time for an object in one dimension, generate the other plot (velocity or position).
    a. Generate a qualitative plot (general shape without numbers) showing when the position or velocity is increasing, decreasing, positive, and negative. This includes using the fact that position vs. time is adequate to generate velocity vs. time, but you can't go the other way without additional information (e.g. initial position).
    b. Starting from position vs. time, generate a quantitative plot (with numbers) of velocity vs. time by finding the derivative (slope) of the position plot at different times.
    c. Starting from velocity vs. time, generate a quantitative plot (with numbers) of position vs. time by finding the integral (area under the curve) of the velocity plot for different intervals. This includes using the fact that the area under the curve of velocity from one time to another gives you *change* in position, not position.

Day 2 – Problem Solving Methods (units, limits, framework) and Algebra

1. Given a formula, be able to analyze its units and check if they are correct.
2. Given a solution to a problem in terms of variables (no numbers yet), check if it makes sense if you plug in extreme values (usually zero or infinity) for different variables. For example, what do you expect when the initial velocity is zero? What do you expect when the initial angle is zero? Does your formula match your expectations? (This includes being able to talk about what happens when different quantities {time, distance, etc.} are approaching infinity.)
3. Be able to effectively use the expert problem-solving framework (picture, key ideas, solution, evaluation). Note that the hardest part of this is the evaluation.
    a. A good picture should show the relevant motion and make clear what is known and unknown.
    b. Good key ideas should make it clear what equations apply to this problem (or to parts of the problem).
    c. A good evaluation should explain how you could have predicted a range of possible values for the answer without doing the calculation you used to solve the problem.
4. Solve an equation for a variable (whether the other terms are numbers, other variables, or both).

5. Solve simultaneous equations for a specified variable, eliminating one (or more) other specified variables. For example, given ($v_f = v_0 + at, \quad v_f^2 - v_0^2 = 2ax_f$), solve for v_f eliminating v_0.

Day 3 – Newton's Laws

1. Given a description in words of an object with forces on it in 1D, draw a free-body diagram.
    a. Identify the object for which you are drawing the FBD.
    b. Identify what forces are acting on the object.
    c. For each force, identify the type of force and what object is exerting the force on what other object.
    d. Give reasonable labels; never use one symbol for two different things or two different symbols for the same thing.
2. Repeat number 1 for multiple objects. This includes identifying third-law pairs.
3. Know when two forces must be the same because of Newton's $1^{st}/2^{nd}$ law vs. Newton's 3^{rd} law.
4. Identify the frictional forces on an object.
    a. From a description of the situation identify whether friction is kinetic or static.
    b. For kinetic friction, apply the rule $F_{kf} = \mu_k F_N$.
    c. For static friction, know when you can and can't assume $F_{sf} = \mu_s F_N$. (You only can assume this when something is at the threshold of slipping.)
    d. Do not assume $F_N = mg$!

Day 4 – Trigonometry

1. Given some angles and/or sides of a triangle, find other angles, sides, and trigonometry functions using the Pythagorean theorem and SOHCAHTOA.
2. Given a figure with angles labeled in one or more places, figure out what other angles in the figure must be equal to the given ones.
3. Vector components
    a. Given the magnitude and angle of a vector, find its components.
    b. Given the components of a vector, find its magnitude and angle.
    c. Given the orientation of a vector in a figure (e.g. perpendicular to a particular surface), use number 2 above to find its angle, and then get its components.
    d. Given a vector and the sides of a relevant triangle, find its components without solving for angles first. (For example, find the components of a force of magnitude F pointing perpendicularly off the tilted surface of a right triangle with specified sides.)
    e. Break a vector into components along tilted axes.
4. Given a description of a problem, figure out the best set of axes to use.
5. Repeat the Newton's Laws intended learning outcomes in 2D.

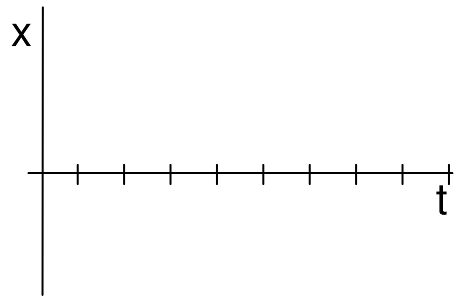
Day 5 – Integration

1. Find the area of a figure by integration.
    a. Break the figure into slices and correctly label all relevant lengths. This includes distinguishing constants, variables, and differentials.
    b. Identify the variable of integration.

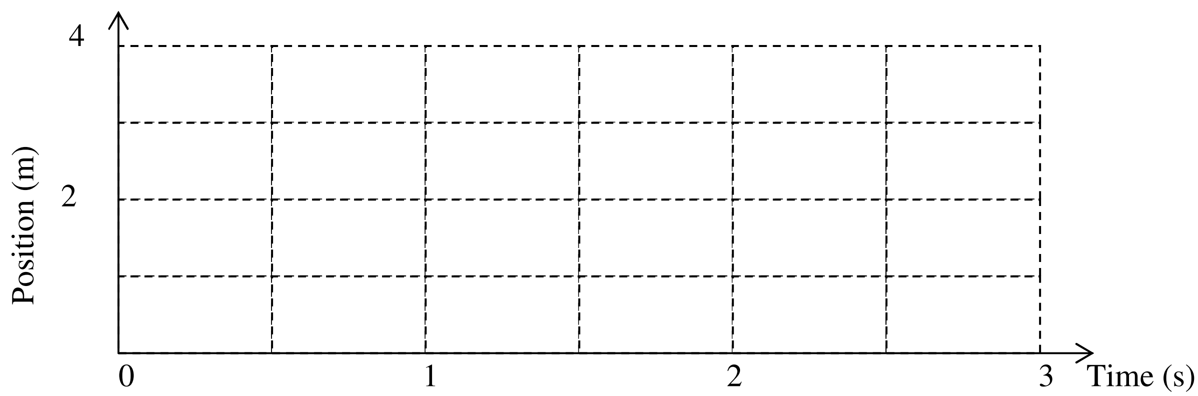
    c. Find the area of each slice and rewrite it in terms of the integration variable. This may include finding the equation of a line that borders the slice.
    d. Integrate to find the area.
    e. Evaluate the answer for units and limits.
2. Repeat all of the above for volume instead of area.
3. Find the mass of a figure by integration.
    a. Set up slices and find their area or volume as above.
    b. Use density to find the mass of the slice.
    c. Integrate and check units and limits.
4. Find the centroid of an area by integration
    a. Identify which direction the slices need to be in.
    b. Break into slices and find their areas (as above).
    c. Integrate to find centroid of area.
    d. Check units and limits and note if you can tell by inspection what part of the figure the centroid should be in.

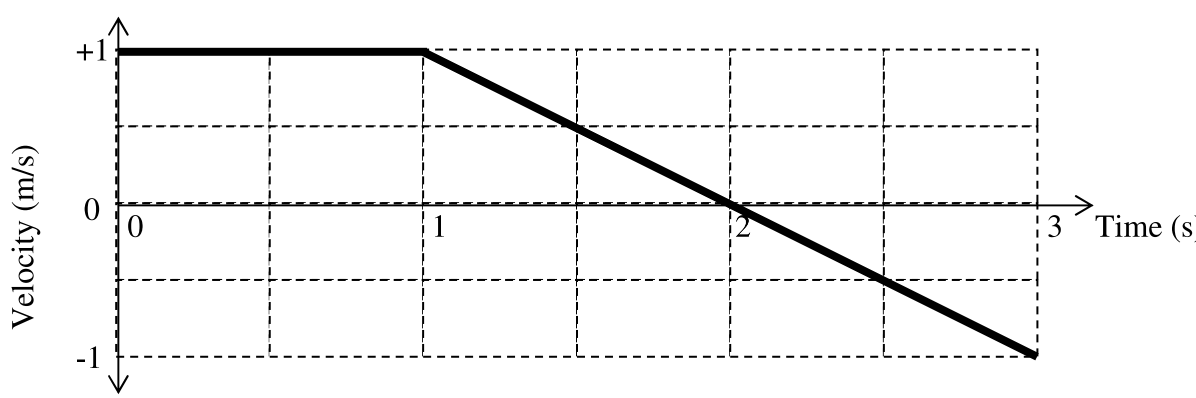
APPENDIX B: Content-Based Pre-Assessment

1. A woman walks forward slowly for 3 seconds and then more quickly for 2 seconds. At this point she stands still for 2 seconds. Then she walks backwards at an increasingly fast pace until she arrives at her starting point, Sketch a qualitative plot of her position versus time on the axes below. You do not need to include any numbers.

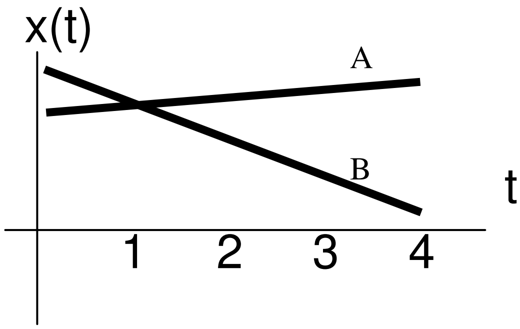


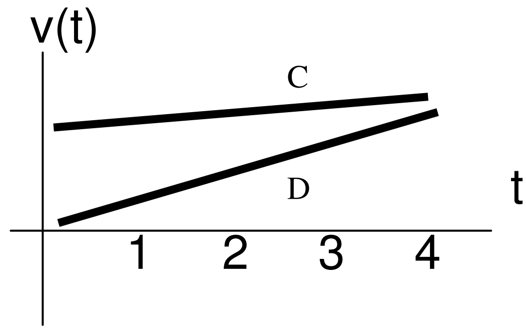
2. The plot below shows the velocity v(t) for an object in m/s. At t=0 the position of the object is 2 m. Plot the position in the lower graph. Be sure to include numbers on both axes and make the shape of your curves clear. What is the object's position at 4 seconds?





3. Below are position versus time and velocity versus time plots of 4 different motions.
   a. Is A or B moving faster?
   b. Do A and B ever pass each other? If so at what time(s)?
   c. Is C or D moving faster?





4. Solve for t_f in the following equation: $0 = y_0 - \frac{1}{2} g t_f^2$.

5. Solve for y in the following set of simultaneous equations. The quantities a and b are constants and x is a variable that must be eliminated in your solution.
   $x + 2y^2 - a = b$
   $x + y^2 = b$

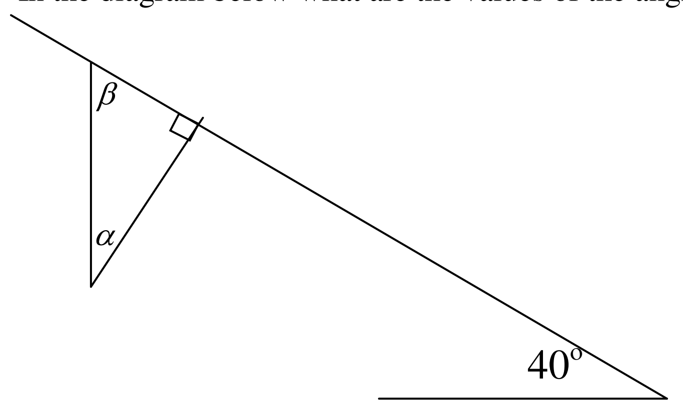
6. Your friend asks you to check calculations for the volume of an object. Her answer is volume $= a^3 + b^4\pi/a$ (where a and b are dimensions in meters). Do the units of her answer make sense? Briefly explain.

7. A child is standing on a wagon. Draw the free-body diagram of the wagon. For each force in your diagram, write in parentheses the Newton's third law pair of that force.

8. Mary takes a helicopter ride while holding a book in her lap. Her mass is M_M, the book's mass is M_B, and the helicopter's mass is M_H. If the helicopter is accelerating upwards, draw a free-body diagram of Mary and a free-body diagram of her book.

9. You drive D miles at an angle θ North of East. How far east do you end up from where you started?

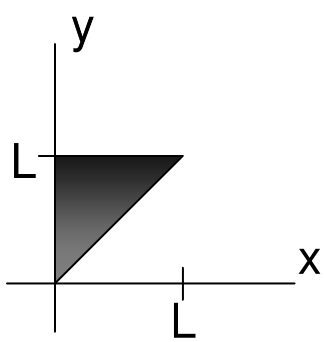
10. In the diagram below what are the values of the angles α and β ?



11. A block of mass m rests on a plane that is inclined at a 10° angle. Draw a free-body diagram of the block and label all forces. What is the magnitude of the component of the gravitational force on the block that is parallel to the plane?

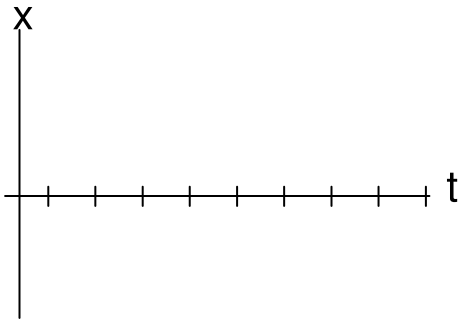
Attempt this last problem only if you have finished and checked your answers on the first 11 problems.

12. The 45-45-90 triangle shown below has a density (mass per unit area) of cy^3, where c is a constant. Find the mass of the triangle.

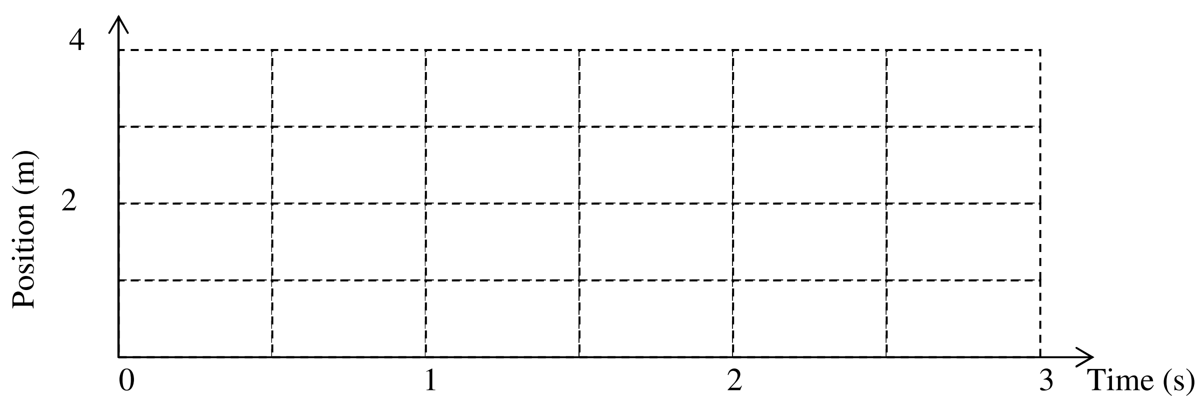


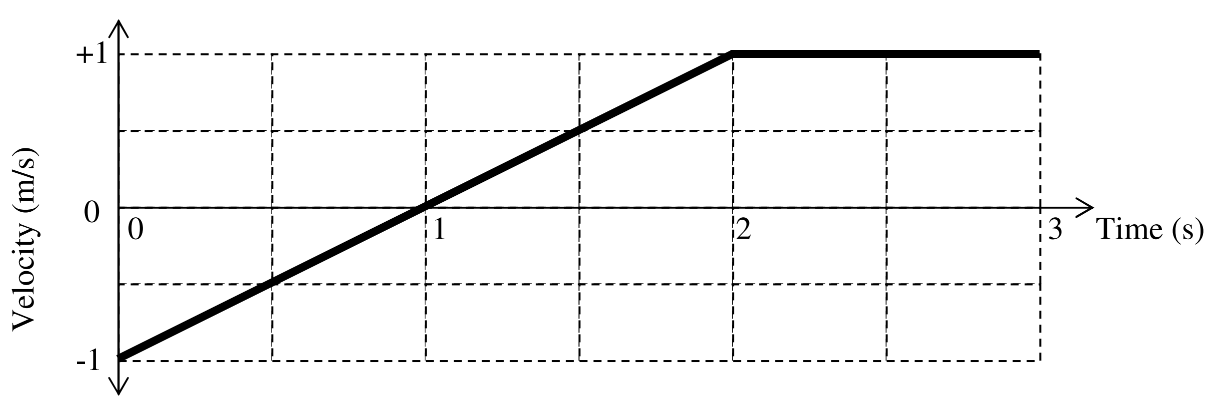
APPENDIX C: Content-Based Post-Assessment

1. A man runs forward for one second, then gradually slows down until he comes to a stop at 3 seconds. He remains still for 2 seconds before walking slowly in the other direction until he ends up back where he started. Sketch a qualitative plot of his position versus time on the axes below. You do not need to include any numbers.

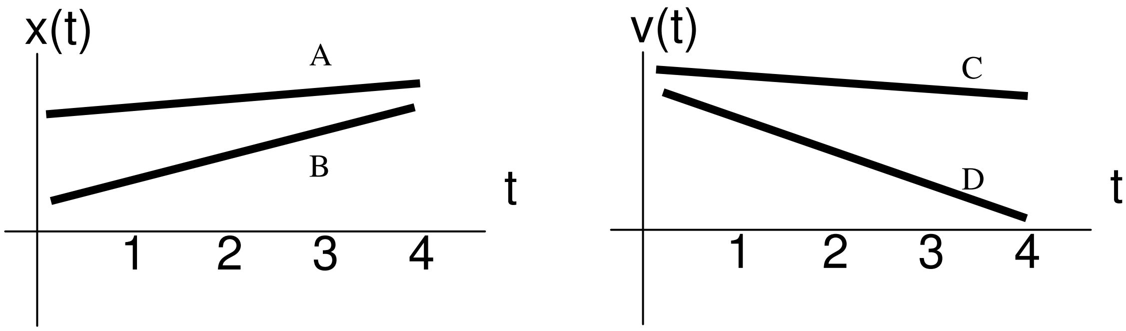


2. The plot below shows the velocity v(t) for an object in m/s. At t=0 the position of the object is 1 m. Plot the position in the lower graph.. Be sure to include numbers on both axes and make the shape of your curves clear. What is the object's position at 4 seconds?





3. Below are position versus time and velocity versus time plots of 4 different motions.
   e. Is A or B moving faster?
   f. Do A and B ever pass each other? If so, at what time(s)?
   g. Is C or D moving faster?



4. Solve for v in the following equation: $P_1 + \rho g y_1 + \frac{1}{2}\rho u^2 = P_2 + \rho g y_2 + \frac{1}{2}\rho v^2$.

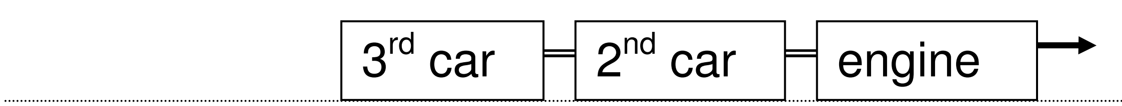
5. Solve for y in the following set of simultaneous equations, eliminating x:

$$x\,y + 6y^2 = 5$$
$$x + 4y = 0$$

6. You just finished a test and are checking your work. On a problem that asks you to find the velocity of a train, your answer is velocity = v_0 + MR/t (where v_0 is the initial velocity of the train, M is the trains mass, R is the radius of the curved track and t is time from the station. Do the units of your answer make sense? Briefly explain.

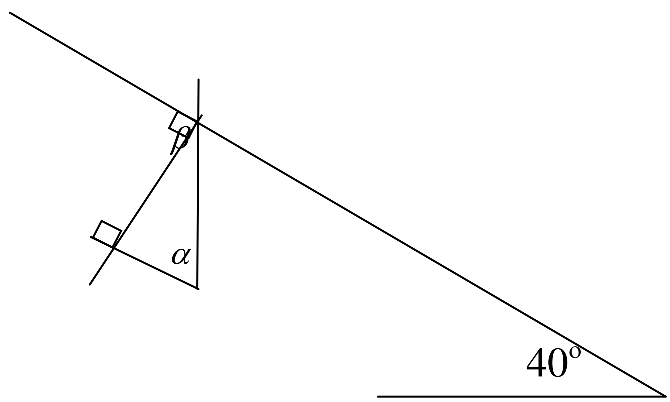
7. A book sits on a table. Draw the free-body diagram of the table. For each force in your diagram, write in parentheses the Newton's third law pair of that force.

8. A train is being pulled by an engine car. There are three train cars, including the engine, and each car has a mass of M. The train is accelerating at a constant rate and you may neglect friction. Draw the free-body diagrams of the second and third cars.



9. A ladder of length L leans against a wall, making an angle of θ with the ground. How far is the bottom of the ladder from the base of the wall?

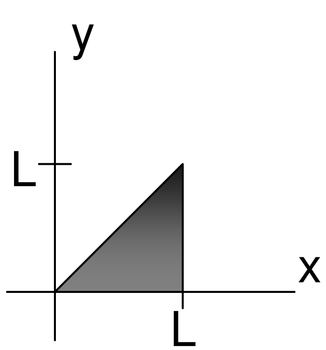
10. In the diagram below what are the values of the angles α and β?



11. A book of mass m rests on a ramp that is inclined at a 20° angle. Draw a free-body diagram of the book and label all forces. What is the magnitude of the component of the gravitational force on the book that is perpendicular to the ramp?

Attempt this last problem only if you have finished and checked your answers on the first 11 problems.

12. The 45-45-90 triangle shown below has a density (mass per unit area) of cy^2, where c is a constant. Find the mass of the triangle.



Appendix D: The Expert Problem Solving Framework

By far the most useful thing you can learn in a math/science/engineering course is the right approach to solving problems. The following problem-solving framework, with minor variations, is the approach expert scientists and engineers use. The sooner you start practicing this method the better you will do in these fields.

The steps involved are described briefly below, and then illustrated through an example. Virtually every homework solution is another example that you can look at to see this method being used.

Draw a picture: The first thing you should do in solving almost any physics problems is draw a picture showing the interaction(s) you are trying to describe and what quantities are involved (velocities, forces, …). In some cases you may need to draw more than one picture, e.g. before and after a collision. Using this picture, you should be able to translate the information in the problem into specific variables that you can try to relate mathematically.
Identify the "Key Ideas" that will allow you to solve the problem: What physical principle(s) can you use to solve the problem? Can you use conservation of energy, Newton's laws, or the relationship between velocity and acceleration? The key idea should be some physical concept that allows you to write down an equation relating the variables in the problem. This step is sometimes called building a model of the problem.
Solve the equations: Once you've translated the problem into a set of math equations, you should then be able to solve those equations for the quantity you want to know. Whenever possible, solve first using symbols (v, F, …), and only plug in numbers at the very end. This will greatly reduce your odds of making careless errors.
Evaluate your answer: You might think you're done after the last step, but the evaluation step is one of the most important things scientists and engineers do. If you are asked to find the radius of the Earth and you get the answer 10 miles, you should realize that you made a mistake.

Checking units - The other step: The best way you can check your answers in any calculation is to check if the units are correct. If you end up saying that the velocity of an object is equal to its height times its mass then you made a mistake; distance times mass does not give velocity. Some people include this as part of the evaluation stage, but I've listed it separately to emphasize the fact that you should be doing this throughout your calculation. Every time you write an equation you should check if it has correct units. This is the fastest, easiest, and most reliable way to catch mistakes.

Appendix E: Dynamics Conceptual Framework[3]