Exemplars in Problem-Solving in Physics Instruction

by

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Abstract

Physics students struggle to solve problems outside the examples that rely on specific equations provided by textbooks. In this curriculum project, students were provided video exemplars as additional resources to determine the effect on student's problem-solving abilities. During the curriculum implementation, students were asked to view instructor created videos on physics concepts and problem-solving. Embedded in the videos were questions related to key concepts and problem-solving specific to the unit content. Videos were selected from YouTube as exemplars of specific ill-defined and well-defined problems in each unit of study. Within each unit, students were given an ill-defined and well-defined problems to solve in small groups along with a problem-solving rubric to assess against.

Keywords: physics, problem-solving, exemplars, ill-defined problems, well-defined problems

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Table of Contents

List of Tables

List of Figures

Chapter One – Introduction

The Purpose of the Project

Physics is coupled to daily observations by ordinary people and as part of science curricula is positioned to help students make sense of those observations. Within science curriculums, physics topics are often utilized in providing real-world experiences with problem-solving. At Evergreen Lutheran High School, teaching physics consists of helping and guiding students to learn and understand concepts and solve problems. Many students understand the concepts and basic equations in physics as presented by the curriculum. Students also can follow formulaic processes to solve simple plug and play equations. Yet students also are uncertain navigating a path towards solving problems that are not defined by a single equation in a textbook.

The transfer of skills in physics from concepts and simple equations to more rigorous and demanding problem solutions is an educational difficulty for students. This capstone project is an endeavor to design a problem-solving curriculum for a semester in a physics classroom. Content delivery will be modified with technology so that learning is assessed with more parallelism and student control of learning. As a supplement to the content that will be taught, the project will incorporate formative assessment tools into the curriculum that will enhance student exploration of problem-solving solutions. The curriculum changes will provide students with methods to assess and connect their problem-solving skills to a wider variety of problems.

Importance of the Project

Science helps us understand the natural world in which we observe and live. The application of mathematics in the world around us gives life and meaning to the subject of math, which many students consider dull and unimportant unless it has applications. Physics is an excellent subject to marry mathematical concepts, rules, and theorems to the physical world in which we live. The subject of physics should spark student learning and finally answer their often-repeated question in mathematics courses, “when will I ever use this stuff.” A course in high school physics merges concepts, vocabulary, and mathematics to develop foundational building blocks in problem-solving. Additionally, the physics course should engage students’ prior knowledge, experience, strategy selection and decision-making skills.

Making students into strong, efficient problem-solvers is important for today’s workforce and society as problem-solving is an interdisciplinary skill. The recent and continuing thrust of STEM education is the dominant example of the disciplines of science, technology, engineering, and mathematics where problem-solving is important to producing high school graduates who are active, critical-thinking members of our society. Students however struggle with problem-solving in many of the STEM disciplines. Physics is a high school course that can touch all the STEM disciplines and so has strong potential for interdisciplinary problem-solving applications.

In a world progressively dependent on technology and applied science, the need for problem-solving is growing as well. This project is important for my school’s science curriculum which uses textbooks and resources that are grounded in a traditional approach that focuses on equation memorization and lacks student interactivity. The current textbook gives single worked examples of problems followed by four to six practice problems. The curriculum resources provide many activities and exercises for students. The curriculum includes problem-solving exercises that range from single equation solutions to mixed problems that require more complex solution pathways. However, almost all complex problems lack exemplars and rubrics that would assist students in learning superior problem-solving processes.

Project Goal

Upon completion of this curriculum project, students in Physics will receive curricular resources that will include exemplars of physics problems requiring multiple pathways, more than one equation, and require more complex decision-making skills. The curriculum will give students formative assessment tools for problem-solving exercises. Students will show evidence of mastery of the tools for problem-solving in chapter and unit summative assessments.

Chapter Two – Literature Review

Many teachers would agree that problem-solving engages higher order thinking skills that are significant to student learning. Higher order thinking skills are emphasized through teaching STEM – science, technology, engineering, and mathematics. Problem-solving is a complex activity that engages domain knowledge, mental models, ampliative skills, and metacognitive skills in the learner (Jonassen, 1997). The activities of problem-solving and thinking skills development are critical to a growing number of vocations. Solving complex, nonroutine problems is recognized as essential in technical fields by the National Academy of Science and other technical institutions (Docktor, 2016). Thus, requiring secondary students to solve problems, especially in physics where it is foundational for disciplines inside and outside of STEM, is beneficial.

However, within high school curricula, students who engage in courses with problem-solving components struggle to develop those skills associated with solving nonroutine problems. This is observable and measurable in the physics classroom. Students are unable to transfer problem-solving skills that they do develop to novel problems in different contexts (Jonassen, 2003). Students sometimes lack domain knowledge, understandings and information that must be applied in a particular field, forcing them to use weak methods such as generalized problem-solving heuristics (Maloney, 2011). Problem-solving competence also relies on the student's conceptual model of the problem at hand (Schoenfeld, 1985).

What students are actually learning varies significantly as problems provide them multiple solution pathways which fit on a spectrum from more to less efficient. There are also many strategies for solving problems in physics. Four distinct classes of strategies were identified to represent knowledge that a student might hold after they have learned to solve problems (Simon, 1974). These strategies are labeled as rote, goal recursion, perceptual, and move-pattern strategies.

Educators should be aware that dissimilar strategies have different degrees of transferability. Also, diverse strategies will place different amounts of burden on working memory and thus cognitive load. These diverse problem-solving strategies may require different learning processes. This can be positive because learning new problem-solving strategies has been shown to improve a learner's problem representation (Alibali, 2009). In understanding problem-solving behavior in learners, educators will need a solid grasp of the strategies that underlie the learner's behaviors.

Much of the research on problem-solving targets the differences in novice and expert problem solvers. Educational research is seeking to know how novice students approach and grow in their problem-solving skills. When students engage in a qualitative analysis of problems prior to suggesting solutions and equations, a cognitive shift is observed where novices begin thinking more like experts (Larkin, 1980). Novices focus on quantities to be found, writing equations, and connecting variables to known values specified in problems. Experts recognize patterns of information, select and apply principles, and allow models to collect information and use it to generate new information. One approach is to use an epistemic game for analyzing the novice to expert transition (Tuninaro, 2007). A solid approach for moving from novice towards expert is to use worked example – problem pairs. Conventional problems typically contain a set of givens along with a solution goal. Worked examples aid students by additionally showing learners the steps required to reach the goal. Research on worked example – problem pairs has been shown as effective for learning and transfer in problem-solving (Van Goh, 2011).

Another area of importance in problem-solving research is that of problem type definitions. Well-structured problems have well defined goals, constrained logic and predictable solutions. In contrast, ill-defined problems have a mixture of unknown initial states, problem elements, changing goals, and uncertain logic (Jonassen, 2003). In a meta-analysis, researchers effectively sorted types and found positive effects for student cooperation in gaining skills with both well-structured and ill-structured problems (Qui, 1995). In related research, horizontal transfer problems match the definition of well-defined problem types while vertical transfer problems are equivalent to ill-defined problem types (Rebello, 2007). Ill-defined problems represent real world problems and situations that students are likely to encounter, so they have value when used in a physics curriculum (Maloney, 2011).

Problems, including those in physics, have to be represented as a cognitive structure (Chi, 1981). The representation is constructed on the problem solver's level of domain-related knowledge and can include many components. Those components can be the problem "givens", the desired outcome, and the problem-solving operators. Additionally, there are representational inferences and abstractions to consider in the cognitive structure. Problem representation is the key to problem-solving among novice learners as well as experts (Jonassen, 2003). By evoking particular internal problem representations, there is an increased likelihood that those representations will produce positive transfer. Learners who struggle to match their internal problem representation to the external problem representation will fail to solve the problem presented to them

(Rebello, 2007). In physics, external representations often are manifested in pictorial diagrams that must be analyzed to tell a conceptual story based on the spatial relationship among objects (Tuminaro, 2007).

The concept of representation is also related to research on memory of problem-state configurations. Good problem solutions in physics might result from the chunked representation abilities of students (Chi, 1981). Novices often lack the ability of experts to represent abstracted solution methods. There is similar evidence in chess problem-solving abilities where differences did occur in chunk size with chess experts' chunks being far larger than those of novices (Sweller, 1988). Sweller also documented other research that shows this difference in chunk size between experts and novice in other knowledge domains.

Knowledge maps are visual aids for presenting complex information that resides within resources on topics and for showing the patterns of knowledge flow. Knowledge maps have proven to be useful chunking reference tools for dealing with quantities of complex information in problem-solving. In college chemistry and biology, volunteer mapping groups strongly associated chunks for a mental schema (Lindstrøm, 2009). When teaching novice learners problem-solving, it appears to be important to use knowledge maps as a scaffolding mechanism. Conducting mapping activities may provide an effective learning environment for physics students as they move from novice to experienced problem solvers.

As we discuss working with novices in building problem-solving skills with schemata and cognitive representations of problems, we should also be aware of cognitive load and its link to tasks associated in problem-solving. Cognitive load is the amount of information kept in a person's working memory (Kirschner, 2009). Keeping student's cognitive load balanced is important. The cognitive load for individuals can be mitigated by using collaborative work groups. There are transactional costs on cognitive load which include the initiation and maintenance of communication and coordination in collaborative group work, but those costs can be divided among group members.

There are recommendations for instruction that come from cognitive load theory (DeJong, 2010). Teachers should present material that aligns with the prior knowledge of the learner known as intrinsic load. Teachers should avoid non-essential and confusing information called extraneous load. Finally, teachers should stimulate processes that lead to conceptually rich and deep knowledge, also known as germane load. Another pedagogical principal to minimize cognitive load is to use guided instruction where appropriate (Kirschner, 2006). Guided instruction should help students avoid extraneous load and build up germane load.

One remaining aspect of problem-solving remains to be discussed here. A barrier to the development and dissemination of physics material is the lack of an assessment tool for measuring the quality of a students' problem-solving (Docktor, 2016). In recent research, the design of a rubric with categories and scoring criteria has been a priority. The rubric design from (Docktor, 2016) and her colleagues has been validated using a framework from the *Standards for Educational and Psychological Testing*.

The assessment instrument in the form of a rubric, assesses written solutions to physics problems using five independent parts (Docktor, 2016). Affective qualities such as motivation, interest, and beliefs about physics that are not usually evident from written work are not assessed by this rubric. The rubric is not meant for grading purposes but attempts to measure characteristics of expert-like problem-solving behavior while maintaining independence from specific pedagogies.

A recent pedagogical strategy within curricula is the modeling of problem-solving using videocasts. Research has shown the proficiency at solving standard textbook exercises at the end of each chapter does not promote proficiency at conceptual problem-solving (Heller, 1992), while the reverse is true – proficiency at conceptual problem-solving aids in promoting solutions to textbook problem-solving exercises (Reif, 1982). Recently (Sayer, 2018) has stated that pedagogically, it is an open question on whether there are benefits to video screencasts' impact on improving student learning. However, the use of screencasts was shown to increase students' sense of ownership in problem-solving (Van Dusen, 2012).

Student learning is improved when active engagement is encouraged in problem-solving. Active engagement is not simply watching videos, but actively responding to conceptual knowledge presented in videos by answering probing questions. Even greater learning is activated when students must create their own videos that show their thinking and problem-solving processes. Students must collaborate on physics concepts, communicate clearly through narration of a video solution, and review and assess each other's videos in the context of their own understanding (Weliweriya, 2017).

In 2000, a couple of professors authored an article on the inverted classroom. Inverting the classroom means that events that have traditionally taken place inside the classroom now take place outside the classroom and vice versa (Lage, 2000). The technology initially used computers and VCRs to view the lectures at home. PowerPoints with audio presentation components were also popular in early inverted classrooms.

When compared to traditional classroom instruction, inverted classrooms required lower student enrollment to capitalize on the strengths of faculty – student interaction (Lage, 2000).

The popularity of this inverted lecture did not grow much until 2007, when YouTube and other Internet video streaming services became easily accessible. Even so, not all classrooms lend themselves to being “flipped”. Courses that are inquiry-based or those that do not have an abundance of factual content for students to learn might not benefit from flipping. With that caveat, flipped learning advocates and chemistry teachers Aaron Sams and Jon Bergmann found shifting lower levels of Bloom’s taxonomy out of the class enabled time in class to be shifted to the upper end of the taxonomy (Sams, 2013).

As research continues on improving problem-solving in physics, so too does research on appropriate taxonomies that align to student learning objectives. *The New Taxonomy of Educational Objectives* (NTEO) is a two-dimensional framework that systems of thinking and domains of knowledge as the two dimensions. The taxonomy’s educational value as a tool in physics is to address problem-solving by identifying the relevance of knowledge domains and cognitive processes and making a clear distinction between them in problem-solving (Teodorescu, 2013).

Research shows that higher interactivity in video use improves learning and outperforms passive learning (i.e. watching a video) (Zhang, 2006). The evolution of applications like “PowerPoint” that now include interactive online recording elements and websites such as “EdPuzzle” make interactivity a part of flipped instruction to help improve student learning.

Chapter Three – Implementation

Introduction

The researcher chose to tackle the problem representation component of problem-solving as it relates to transfer using specific physics units of study during the second semester. The units of study are thermodynamics and electrostatics. High school students engaged in curricular materials using video tools alongside traditional pencil and paper work. Video tool integration occurred via two primary methods.

Knowledge Building

Students accessed videos that engaged concepts specific to the aforementioned units of study. This curricular change initially engaged students at the knowledge building level of Bloom's taxonomy prior to problem-solving exercises. This component of the curriculum follows a flipped instruction model as students complete the video activities outside of classroom instruction. Students viewed videos between 7 to 12 minutes in length with specific questions that students must answer at multiple junctions throughout the video. Breaking the video into segments and asking students to answer questions as regular manageable intervals assisted with chunking in learning concepts and conceptual models. The current curriculum contains only computerized conceptual mapping exercises as a summary activity for each textbook chapter. After completing the video activities, students completed the corresponding computerized concept mapping exercise.

Well-defined Problem-solving

Students accessed instructor provided videos as exemplars of well-defined problems from the current Physics curricular materials. The students answered questions about the processes involved in the problem-solving video. Students were asked to identify assumptions, problem provided information, potential mathematical relationships, and equations that allow them to engage in problem-solving. Students also answered questions to show their knowledge of the concepts involved in the problems. Students continued to practice problem-solving with well-defined problem types, with the instructor providing timely feedback on the above-mentioned component's usage in problem-solving. The instructor provided comments on the video questions to reinforce conceptual knowledge and good problem-solving habits.

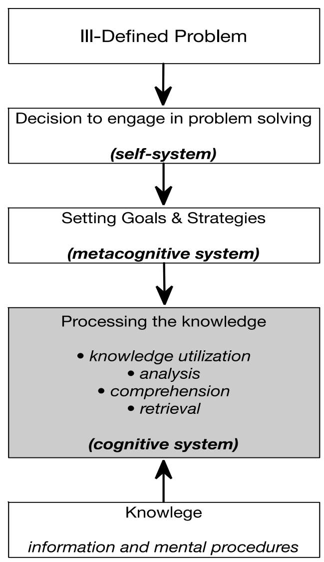

Figure 1: NETO

Student Demonstration of Problem-solving

Next, students created videocasts. Creating videos provided students with an opportunity to engage in higher order thinking skills in educational taxonomies. One of the latest modifications to Bloom's Taxonomy is titled *New Taxonomy of Educational Objectives* (NTEO). The skills of interest can be found in the diagram in figure 1 in the shaded box. The NTEO skills of interest in physics problem-solving include analysis and knowledge utilization at levels 3 and 4 respectively. Creating videocasts that require analysis and knowledge utilization skills engaged students' deeper cognitive thought processes while solving physics problems. The videocast format provided the current and future classes with exemplars.

Lesson Plan Modifications

I modified lesson plans and activities around the processing of knowledge. Knowledge mapping activities were used to confirm students are grounded in that conceptual knowledge. In addition to building knowledge comprehension, I focused on the two components that first affirm conceptual knowledge and second build higher order thinking in the areas of analysis and knowledge utilization.

First, conceptual knowledge affirmation and application included students processing video exemplars and practice problems that are well-defined problem types. This engagement with the exemplars and practice problems was aimed at two goals - to sustain student conceptual knowledge through reiteration and make the use of physics problem-solving principles habitual. Problem-solving principles include identification of assumptions, extracting a problem's given information, recognition of mathematical relationships, and equations that allow application of those relationships. I reviewed and modified specific well-defined problems for the flipped video activities. Videos of well-defined problems were instructor selected or created and then developed with specific questions to fulfill the two goals.

Second, I asked students to create videocasts that solve ill-defined problem types within the physics concepts in the current unit of study. Students built problem-solving solutions in their videocasts that demonstrated both analysis of the problem in conjunction with knowledge utilization specific to the problem's context. Student's videocasts were to demonstrate their mastery of problem-solving principles throughout their process.

Curriculum Implementation

Lesson plans began with the use of a short inquiry style presentation to introduce new topics with appropriate questions. The presentation's primary reference material originated from PowerPoints provided by the textbook curriculum. Basic vocabulary, principles, and equations were introduced in these PowerPoint slides. The presentation's inclusion of a primary problem-solving example from the textbook were moved to flipped instruction. When applicable, students continued to participate in inquiry laboratory activities that supplement the current curriculum.

Laboratory activities were hands-on activities or virtual interactive activities using online resources such as "Physics Education Technology (PhET) Interactive Simulations". The PhET project was founded at the University of Colorado Boulder and is a collection of research-based interactive computer simulations for teaching and learning a variety of sciences, including physics. The simulations emphasize the connections between real-life phenomena and the underlying science and help make the visual and conceptual models of scientists accessible to students.

Flipped Instruction

In the next step of the curriculum, lesson plans utilized the flipped learning component where students engaged in conceptual knowledge building using several work example-practice pair interactive videos. The curriculum process for developing the flipped instruction is shown in Appendix D. "EdPuzzle" were used for these knowledge building activities. "EdPuzzle" is a tool that allows teachers to embed probing questions at points throughout a video. Students were required to answer the questions before they could continue watching the next video segment.

The answers gathered help teachers gauge student readiness to tackle ill-defined type problems. The instructor can provide comments back to the student as feedback on their answers. Feedback on conceptual knowledge and problem-solving principles should build students skills and confidence in problem-solving. Practice problems completed via traditional pencil and paper or digital pencil and paper were used for periodic instructor assessment of concepts and problem-solving principles. These practice problems also gave students experience with the rubric (Appendix C) used later in the curriculum.

Student Videocast Problem-solving Exercises

After students successfully showed concept knowledge readiness, the instructor matched students to ill-defined practice problems from the curriculum publisher's resources and other online sources. Students worked in small groups of 2 to 3 students during classroom time to solve practice problems. Student groups used a research developed rubric (Appendix B) to peer assess each other's problem solutions during this formative assessment period.

Finally, students completed problem-solving exercises of ill-defined problems with the final deliverable product being the creation of a videocast. The open-ended problem types were designed to reflect real-world situations that engage the analysis and knowledge utilization skills to be development in students. Students used the rubric to self-assess their work and assess their peer's work. Students presented their problem-solving solutions to the ill-defined problems in class using technology such as whiteboard, projectors, and/or computing devices. The presentation was done prior to submission of the final videocast product.

A flowchart of the curriculum implementation process with decision points shown as diamond shapes can be seen in figure 2.

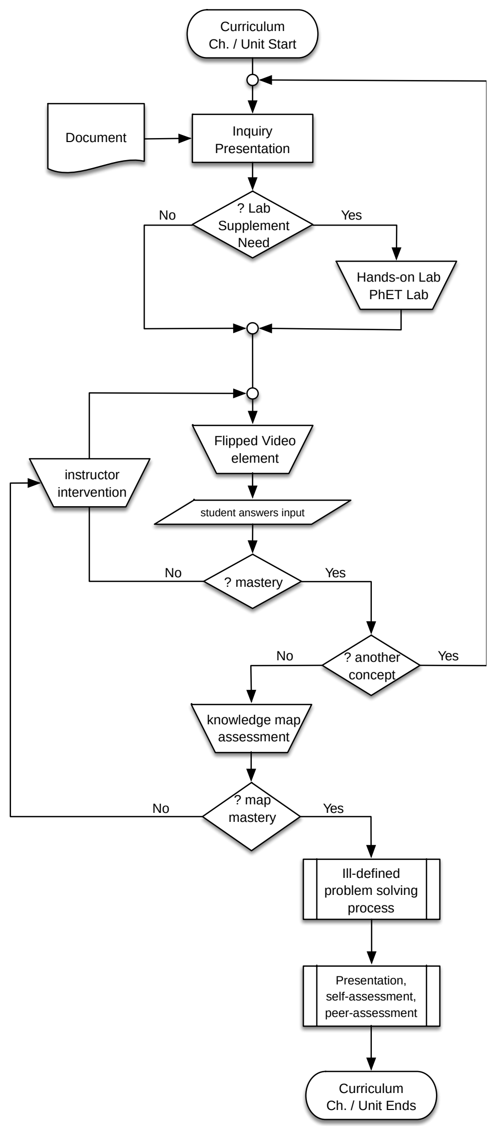

Figure 2 - Curriculum Implementation Flowchart

Instructor interventions included direct instruction on conceptual knowledge and supplemental problems of a well-defined type. Hands on laboratory activities included those aligned to the textbook publisher's resources and used the equipment available in the science classrooms.

Artifacts

During the second semester, the instructor created videos covering the content for the thermodynamics and electrostatics units of study. Specific topics in electrostatics included electric forces, fields, energy, power, capacitance, resistance and current. The video lectures included PowerPoint slides with the instructor's head and shoulders overlaid on top in the lower right corner. Where appropriate, visual concept animations and simulations were inserted into the videos.

The video recordings were then uploaded to the EdPuzzle website. The instructor then embedded questions at specific points in the video. These questions included open-ended type, multiple choice, and simple calculation problems that included the sample problems within the chapter sections and the review questions at the end of each chapter. This gave the students opportunities to show their mastery of concepts and mathematical relationships as they were learning the material.

EdPuzzle activity was primarily completed outside of class with little instructor interaction. The instructor provided type-written feedback online to the student's open-ended responses to reinforce concepts and mathematical relationships. Individual feedback in EdPuzzle also addressed specific misconceptions by individual students. Any broad misconceptions were addressed in class for all the students to reflect upon.

After each sectional EdPuzzle video, students were given well-defined problem-solving exercises to complete. The majority of these exercises were done in class with students checking their work with peers and the instructor. These exercises could be done either on paper or directly on the student's computers using digital ink and pen. Students were asked to take pictures of their handwritten problem-solving exercises to upload to our course digital notebook. This aided the instructor in providing students with timely digital feedback online without the turnaround time that paper grading requires.

Towards the end of a unit of instruction, the instructor assigned an ill-defined problem that was to be solved in student groups. Student groups were assigned randomly for these ill-defined problem-solving activities. The digital notebook structure allowed group collaboration among members of the small groups. Students were required to use the assessment rubric given to them at the beginning of the curriculum implementation timeline. The student group work was recorded digitally using the course digital notebook.

Two summative assessments were given to students on the two major units of study – one on heat and thermodynamics and the other on topics covered in electrostatics. Problems on these assessments were a mixture of well- and ill-defined problem types. Ill-defined problem types were assessed using the rubric to give a point value for grading purposes.

Assessment Plan

Two forms of assessment were used for data collection. The primary method of assessment was the use of a survey. Students were given a survey on the physics curriculum twice during the semester of instruction. The first survey (Appendix A) was given at the start of use of the new curriculum. An end-of-course survey was administered at the end of the course (Appendix B). The survey assessed student attitudes towards physics in general and problem-solving specifically using a Likert scale. Open ended questions were asked to elicit ideas for curriculum improvement. The collection of quantitative data was done with midterm and semester problem-solving tests. Both well-defined and ill-defined problem types were differentiated in assessment data.

Data Analysis

Reponses to the survey were compared longitudinally from the two dates during the semester. Data scores were collected for the problem-solving testing done in the heat thermodynamics unit and electrostatics unit. A comparison of the scores of well-defined and ill-defined problem types occurred.

Limitation of the Design

The lack of a standardized test that directly measured growth in problem-solving is the main limitation in this study. Generally, tests produced by the publishers of the textbooks are geared only toward concepts and well-defined problem types. Even the AP subject test for physics lacks ill-defined problem-solving rigor. In the future, perhaps such a problem-solving assessment will be available.

Results

The implementation of the curriculum was a challenging endeavor, but analysis of the results was even more difficult. A written summary of the students' pre- and post-survey responses can be found below. Questions were grouped that deal with the key attributes involved with problem-solving. Attribute groupings include the students' perceived importance of equations, general problem-solving, exemplars, and the importance of visual resources. Graphs illustrate the change in student perception in the pre- and post- survey responses. More detailed survey results can be found in Appendix F.

The results are made difficult to interpret and analyze for multiple reasons. The number of students in this curriculum study was low for statistical analysis. As senior students preparing to graduate, some of students in the physics course demonstrated deteriorating performance in the last quarter on course instruction. The majority of the students in this physics course were also involved co-curriculars that removed them from significant classroom instructional time. The collective group of students missed 13% of course instructional time, with two students missing 21% of course instructional time for the last quarter.

Pre-curriculum Student Survey Results

Prior to the curriculum implementation, students' answers to survey questions involving the importance of equations in problem-solving registered high. Statements numbered 2, 4, 6 and 8 dealt with equations. When asked to rank the statement, "the most crucial step in solving a physics problem is finding the right equation to use" students either agreed or strongly agreed. The majority of students agreed or strongly agreed that "from a proof of a formula, I learn that the equation obtained is valid and it is alright to use in solving physics problems". Students were neutral or disagreed with the statement that "equations must just be taken as givens" and disagreed or strongly disagreed with the assertion that "proofs of equations presented have little to do with the problem-solving skills needed to succeed in a physics course".

Students' responses to the general importance of problem-solving in physics was interesting as well and were represented by survey statements numbered 5, 11, 16. One student disagreed and one student was neutral in regard to the statement "problem-solving in physics basically means matching problems with facts or equations and then substituting values to get a number”. Most students responded to the statement “the main skill that I expect to get out of this physics course is learning how to solve physics problem” with agreement, with one student disagreeing. A majority of students with the statement “learning problem-solving in physics requires that I substantially rethink, restructure, and reorganize the information that I am given in class and/or in the text”.

Students were also asked to respond to statements about auxiliary resources in problem-solving in physics. Statements numbered 14, 18, 19, and 20 dealt with auxiliary resources. Every student responded that they agree with the statement “developing a mental picture and drawing it out helps in understanding physics problems”. When students were asked their preference for textual or video problem-solving examples, students agreed more favorably with the textual approach as compared to the video approach. One student disagreed with the statement “my confidence increases when I watch videos that show methods of problem-solving in physics”, while the other students were neutral, agreed, or strongly agreed.

Statements 1, 3, 9, and 17 prompted responses about example problems, also known as exemplars, in the context of understanding and problem-solving in physics. Students ranked the statement “to understand most of the basic ideas in this physics course, I just read the textbook, work most of the problems, and/or pay close attention in class” either agree or strongly agree. However, the majority of students disagree or strongly disagree that “reading the physics textbook in detail and working through many of the example problems” is important to them. The majority of students agree or strongly agree that “the best way for me to learn physics is by carefully analyzing a few problems in detail rather than by solving many problems”. Lastly, students struggling to make progress in solving a physics problem agree or strongly agree with the statement "If I cannot make progress on a physics problem that is different than the examples presented in class or in the text, but similar in context, I look for an example that matches my particular problem online".

Post-curriculum Student Survey Results

After completing the two units of the modified physics curriculum, students were asked the same survey questions. Student responses to the question groupings showed some changes in their expressed feelings on problem-solving attributes. This instructor notes that one physics student did not participate in the post-curriculum survey and completed the coursework after graduation due to illness. The question grouping means are listed in Table 1 below.

Table 1

Survey Question Averages

Question	Pre-Curriculum	Post-Curriculum	Change
1	4.33	3.25	-1.08
2	4.33	4.00	-0.33
3	3.00	2.25	-0.75
4	3.00	3.25	0.25
5	3.00	3.25	0.25
6	4.33	3.50	-0.83
7	2.33	1.25	-1.08
8	2.33	2.25	-0.08
9	3.33	4.00	0.67
10	3.00	3.00	0.00
11	3.33	4.25	0.92
12	4.00	4.00	0.00
13	4.00	3.75	-0.25
14	4.33	4.50	0.17
15	3.67	3.75	0.08

16	4.00	3.25	-0.75
17	4.00	4.00	0.00
18	3.67	4.25	0.58
19	3.33	2.50	-0.83
20	4.00	3.00	-1.00

Table 1 - Survey Question Averages

The statements 2, 4, 6, 8 about the importance of equations showed some change as students ranked the statement that "equations must just be taken as givens" with stronger agreement. There was a marked shift away from strong agreement to agreement on question 6 that states "the most crucial step in solving a physics problem is finding the right equation to use", with one student disagreeing.

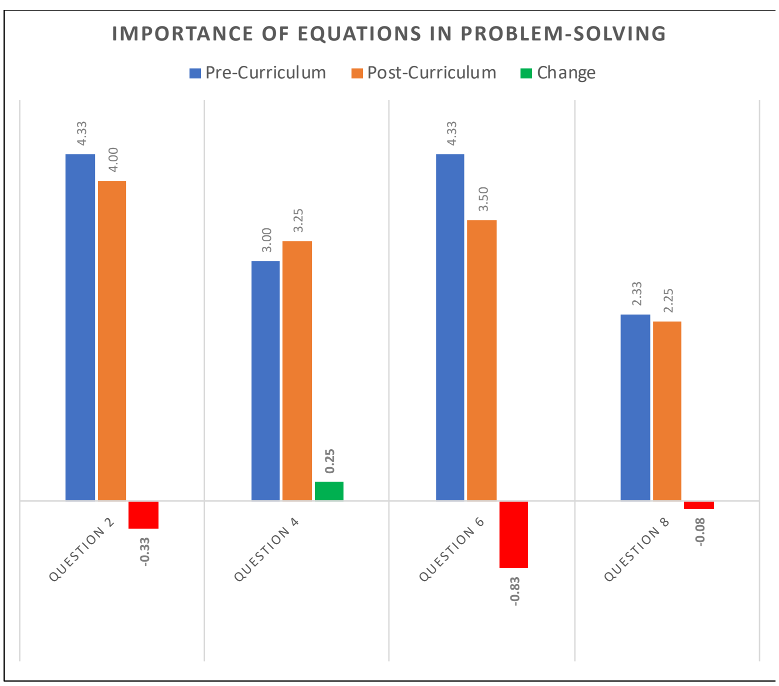

Figure 3 - Importance of Equations in Problem-Solving

Questions numbered 5, 11, 16 dealt with general problem-solving. Little change in student responses were seen in question 5 dealing with definition of problem-solving in the physics context. However, there was a major student shift in the view that "the main skill that I expect to get out of this physics course is learning how to solve physics problems" with all students registering agree or strongly agree rankings. In response to the statement "learning problem-solving in physics requires that I substantially rethink, restructure, and reorganize the information that I am given in class and/or in the text", at least one student changed their response from agree or neutral to disagree.

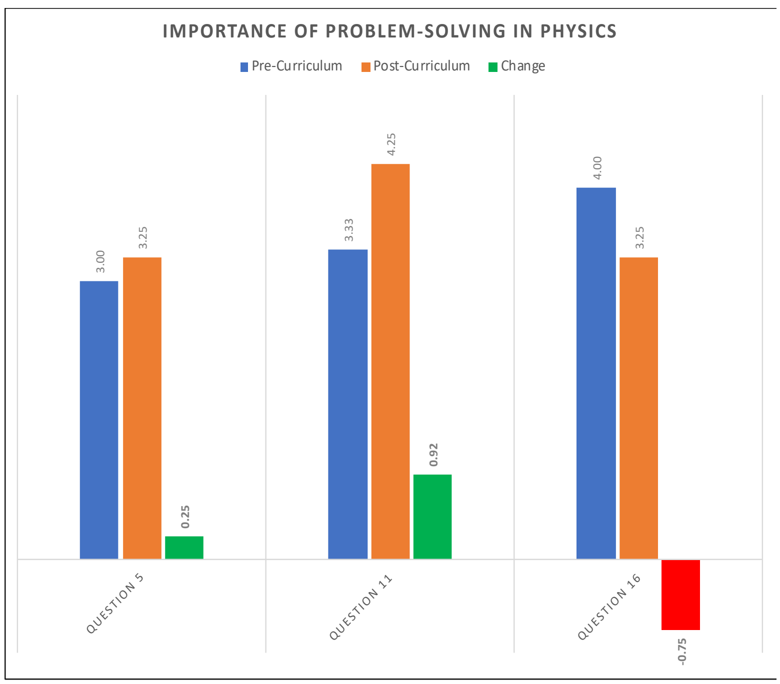

Figure 4 - Importance of Problem-Solving in Physics

The visual resource questions were numbered 14, 18, 19, and 20. Students' responses among questions 14 and 18 remained mostly positive. Both statements 19 and 20 dealing with video problem-solving examples as "the best way to understand other problems" and "my confidence increases when I watch videos that show methods of problem-solving" garnered a response movement toward strongly disagreed. One student whom had strongly agreed in question 20 about videos providing increased confidence no longer felt that way.

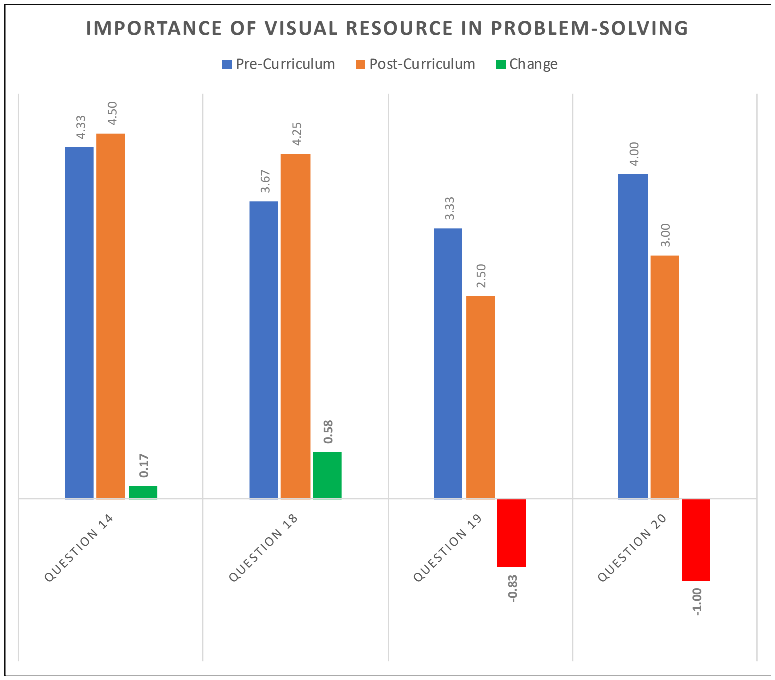

Figure 5 - Importance of Visual Resources in Problem-Solving

Questions 1, 3, 9, and 17 prompted responses about contextual problem-solving exemplars in physics. While the majority of students still agree that “to understand most of the basic ideas in this physics course, I just read the textbook, work most of the problems, and/or pay close attention in class”, one response now indicated strong disagreement with that statement. By majority, students’ disagreement grew with question 3 and the statement “I read the physics textbook in detail and work through many of the example problems given there”. Students’ perception grew more positive from the pre-survey regarding question 9 and the statement that “the best way for me to learn physics is by carefully analyzing a few problems in detail rather than by solving many problems”. Lastly, students’ feeling on question 17 remained unchanged. Students continued to agree with the statement "I look for an example that matches my particular problem online" when struggling to make progress on a physics problem.

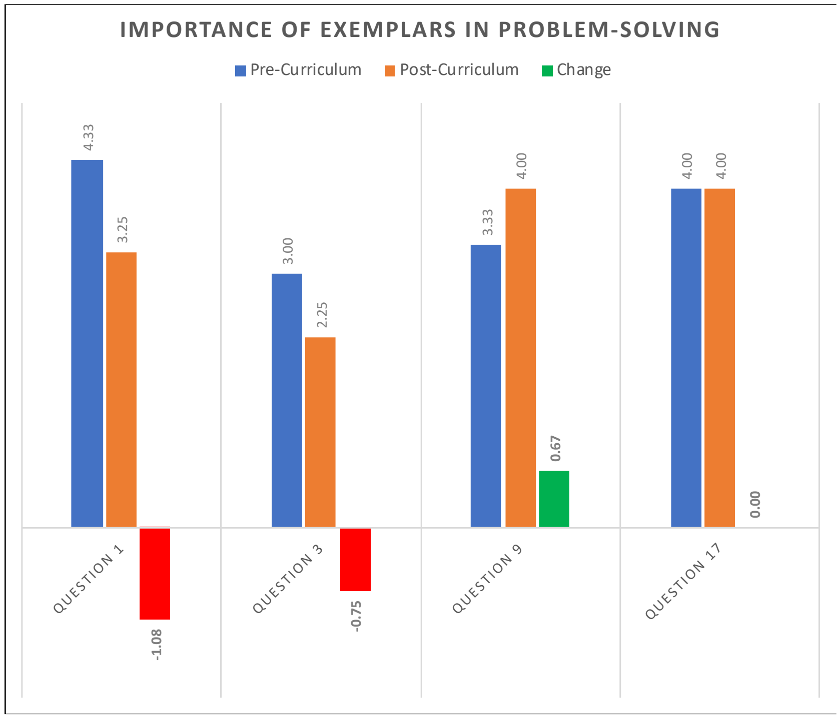

Figure 6 - Importance of Exemplars in Problem-Solving

Problem-solving Type Results

The unit test on thermodynamics contained 22 conceptual questions presented in a multiple-choice format. The problem-solving portion of the unit test contained two well-defined problems and a single multi-part ill-defined problem. Students had 45 minutes to complete this test, which was administered four weeks into the new curriculum changes. One student was given the test at a later date due to illness and chose not to take the problem-solving part of the test.

Of those students taking the thermodynamics unit test, the average problem-solving score was 4.75 out of 11 points for 43%. Well-defined problems represented 7 points and students averaged 53%. Two students garnered points on the ill-defined problem, while three students did not attempt the problem.

The final exam of the semester including the unit on electrostatics contained 54 points of vocabulary and conceptual content presented in short answer and matching formats. The remainder of the test contained problem-solving exercises with a possible 53 points of which 27 points were well-defined types and 26 points were ill-defined types. Students were asked to solve problems worth a minimum of 40 points.

Table 2
Average Student Scores on Ill- and Well-Defined Problems

Problem	Ill-Defined Scores	Well-Defined Scores	No Attempt by Student
55a	1.5 / 2	-	0
55b	-	1.4 / 2	1
56	3 / 6	-	2
57a	-	2 / 2	2
57b		1.5 / 2	3
58	1.8 / 3	-	2
59	-	2.4 / 3	0
60	-	1.33 / 2	2
61	4 / 4	-	3
62	3.25 / 6	-	1
63a	.5 / 2	-	1
63b	-	0 / 2	5
63c	-	0 / 2	5
63d	-	0 / 2	5
64a	-	1.33 / 2	1
64b	-	1.67 / 2	1
64c	-	1.67 / 2	2
64d	-	0 / 2	2
64e	-	1 / 2	3

Table 2 - Average Student Scores on Well- and Ill-Define Problems

The average for all attempted ill-defined type problems was 14.05 out of 26 points. The average for all attempted well-defined type problems was 14.3 out of 27 points. Four of the five students taking the final exam scored well on the vocabulary and conceptual knowledge portion. Students' average score on this portion of the test was 48.6 of 54 points, with the median and mode for the scores being 53 points in both statistics.

Chapter IV: Reflective Essay

Introduction

The purpose of this curriculum project was to examine the representation of problem-solving components in physics units and apply practical changes in the problem-solving learning activities for students. These changes occurred in two units of physics study – thermodynamics and electrostatics. Physics students engaged in using curricular materials in the form of instructor produced videos with embedded questions in EdPuzzle. Two videos from The Mechanical Universe series also were modified with embedded questions for use in EdPuzzle.

The primary video exemplars were instructor selected from iLectureOnline. A few video exemplars were screen recordings of the instructor working ill-defined problems with emphasis on the assessment rubric. The instructor worked completed problem-solving exercise both on a whiteboard and using a projected screen and tablet computer. Students viewed instructor exemplars in the OneNote course notebook. The students also utilized their OneNote course notebooks in presenting their problem-solving skills. In a couple instances, students were asked to record audio commentary on their problem-solving as part of a video screen recording of their OneNote notebook.

Conclusions

A large portion of the curriculum modification consisted of producing videos that included open-ended questions embedded in videos to assist students in preparation for well-defined types of problems. The instructor worked both well- and ill-defined type problems in the OneNote notebook that were projected in class and viewable by students outside of class time. In two instances, problem-solving exercises were screen recorded for video playback. The remaining video exemplars from iLectureOnline were problem-solving exercises of both well- and ill-defined types.

The survey results suggest that students did not find the video resources as particularly helpful in problem-solving exercises in the physics course. The exemplar videos from iLectureOnline had a linear solution pathway for both well- and ill-defined problem types, with the majority being well-defined types. Students struggled with their sense that identifying a set of equations was more important than identifying givens, assumptions, and relationships between physics concepts. Watching the exemplar videos did not seem to change their feeling about problem-solving.

Students were given an instructor tested process for doing video screen recordings to assist in their problem-solving activities. Students experienced unforeseen technical issues in a few cases that extended the process. These technical issues dampened the enthusiasm for completing problem-solving activities. Some students were more adept at using the school's technology platform and used those tools to ask the instructor for technical assistance.

The instructor observed that students can easily identify given information in problems, but too often jump to conclusions about the equations related to that information. Only after an equation did not satisfy the presented problem did students consider assumptions about the problem context and relationships between the information in the problem. This intrigued the instructor since most students could identify appropriate relationships between systems of study in physics during discussion of the unit material.

According to the unit assessments, the majority of students mastered the units' conceptual knowledge including definitions, laws, and mathematical relationships. However, there is a distinct break when comparing in class performance and homework versus test performance in problem-solving even after the modified use of live and video exemplars. The time pressures of testing seem to amplify the students' cogitative load with mostly negative implications for problem-solving performance. This appears to be true in both of the modified curriculum's summative assessments at the end of the units and semester. The percentage of problems attempted along with the points earned for problem-solving parts were quantitatively small. However, students selected equal numbers of points from both ill- and well-defined problem types.

This instructor concludes that building problem-solving skills cannot be influenced positively in the second half of a course curriculum when students' habits and concept of the course's structure are formed in the first half of the course. Developing new habits of problem-solving in a single course that has been modified is also challenging for the student who may have predefined habits from past coursework in mathematics and science. Curricular changes are also potentially affected by the nearness of graduation and the number of co-curricular activities in the period of the curriculum study.

Finally, curriculum modification is a multi-step, cyclical process. As an instructor, I experienced feelings of failure that the majority of the students did not respond favorably to the curriculum revisions. As a curriculum developer, I know more work is needed with specific attention to how problem types are presented in the course. The process of modifying the curriculum consumes more time than initially allotted during the past semester. Any new process has a shake-down time period and takes a few iterations to become manageable by a teacher.

Recommendations

I would recommend that high school physics teachers implementing modifications to problem-solving in the course curriculum do so from the beginning of the class to set expectations and build the habits and skills associated with problem-solving. The habits and skills of analyzing problems in detail along with studying good exemplars are more important to students than memorizing equations and doing large numbers of textbook problems.

This curriculum used videos that students did not find helpful in learning problem-solving processes. In future curriculum studies, a focus on either finding or producing higher quality videos with a focus on problem-solving steps is encouraged by this instructor. In particular, there is ample opportunity and need for better exemplars for ill-defined type problems. In my opinion, each physics unit should have two to three ill-defined problems that are developed by curriculum minded teachers.

Parallel and significant to this curriculum was the use of a digital notebook, OneNote, that can contain the entire curriculum and allows inclusion and easy editing of resources. Students could interact with the curriculum by typing, hand writing, screen recording, audio recording, and embedding their work and resources to the problem-solving process. A better training process for creating screen recordings would help students who struggle with using technology. Students who preferred to use traditional paper and pencil for problem-solving exercises could take a photograph and embed it into their notebook pages. Collecting and using exemplars inside of this OneNote digital notebook makes future physics course modification as part of the improvement cycle.

In summary, while using technology tools like video and digital notebooks have the potential to help students become better problem solvers, the process of making students good problem solvers needs further study. Those future studies may help identify connections in using tools that help teach problem-solving in physics and other curricular disciplines.

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Appendix A

Physics Problem-solving Survey

Student Information (Please complete the student information section first.)

Name: ________________________

Grade: ❑ 11 ❑ 12

Age (in months): ____ months

Sex: ❑ F ❑ M

Academic Information (Read each statement. Mark a single response to each question.)

What was the last math course you completed?
❑ Algebra I ❑ Geometry ❑ Algebra II / Trigonometry ❑ Calculus

When did you take your most recently completed math course?
❑ Last year ❑ Two years ago ❑ More than 2 year ago

Are you enrolled in a math course this semester?
❑ Yes ❑ No

What math course are you taking this semester?
❑ Geometry ❑ Algebra II / Trigonometry ❑ Calculus ❑ AP Calculus

How many high school science courses have you completed prior to taking Physics?
❑ 2 ❑ 3 ❑ 4

Place a check next to the science courses you have completed prior to Physics.
❑ General Science ❑ Physical Science ❑ Biology ❑ AP Environmental Science
❑ Chemistry ❑ Anatomy ❑ Astronomy ❑ Earth Science

How many total courses are you taking this semester (including Physics)? ❑ 7 ❑ 8 ❑ 9

How well prepared do you feel you are in solving problems related to science?
❑ totally unprepared ❑ unprepared ❑ somewhat prepared ❑ prepared ❑ very well prepared

How well prepared academically do you feel to deal with the subject matter of physics?
❑ totally unprepared ❑ unprepared ❑ somewhat prepared ❑ prepared ❑ very well prepared

How well prepared do you feel you are in solving problems related to the subject matter of physics?
❑ totally unprepared ❑ unprepared ❑ somewhat prepared ❑ prepared ❑ very well prepared

Physics Course Expectation Survey Questions

Here are a series of statements which may or may not describe your beliefs about this physics course. You are asked to rate each statement by circling a number between 1 and 5 where the numbers mean the following:

1: Strongly Disagree	2: Disagree	3: Neutral	4: Agree	5: Strongly Agree

Respond to the statements by circling the number that best expresses your feeling. Work quickly. Don't overelaborate the meaning of each statement. The statements are meant to be taken as straightforward and simple. If you don't understand a statement, leave a blank response. If you understand, but have no strong opinion, respond by placing a circle on 3.

1	To understand most of the basic ideas in this Physics course, I just read the textbook, work most of the problems, and/or pay close attention in class.	**1 2 3 4 5**
2	From a derivation or proof of a formula, I learn that the equation obtained is valid and that it is alright to use in solving Physics problems.	**1 2 3 4 5**
3	I read the Physics textbook in detail and work through many of the example problems given there.	**1 2 3 4 5**
4	In this Physics course, I do not expect to understand equations in an intuitive sense; the equations must just be taken as givens.	**1 2 3 4 5**
5	"Problem-solving" in Physics basically means matching problems with facts or equations and then substituting values to get a number.	**1 2 3 4 5**
6	The most crucial step in solving a Physics problem is finding the right equation to use.	**1 2 3 4 5**
7	In doing a Physics problem, if my calculation gives a result that differs significantly from what I expect, I'd have to trust the calculation.	**1 2 3 4 5**
8	The derivations or proofs of equations presented in class or the text have little to do with the solving problems skills I need to succeed in this Physics course.	**1 2 3 4 5**
9	The best way for me to learn Physics is by carefully analyzing a few problems in detail rather than by solving many problems.	**1 2 3 4 5**
10	If I don't remember a specific equation needed for a problem in an exam there's nothing much I can do to come up with it.	**1 2 3 4 5**

11.	The main skill that I expect to get out of this Physics course is learning how to solve physics problems.	**1 2 3 4 5**
12	When I solve most exam or homework problems, I explicitly look for the concepts and patterns that underlie the problem.	**1 2 3 4 5**
13	"Understanding" Physics problems basically means being able to recall something you've read or been shown.	**1 2 3 4 5**
14	Developing a mental picture and drawing it out helps in "understanding" Physics problems.	**1 2 3 4 5**
15	To be able to use an equation in a problem (particularly in a problem that I haven't seen before), I need to know more than what each term in the equation represents.	**1 2 3 4 5**
16	Learning problem-solving in Physics requires that I substantially rethink, restructure, and reorganize the information that I am given in class and/or in the text.	**1 2 3 4 5**
17	If I cannot make progress on a Physics problem that is different than the examples presented in class or the text, but similar in context, I look for an example that matches my particular problem online.	**1 2 3 4 5**
18	I prefer textual problem-solving examples to follow as the best way to understand other problems.	**1 2 3 4 5**
19	I prefer video problem-solving examples to follow as the best way to understand other problems.	**1 2 3 4 5**
20	My confidence increases when I watch videos that show methods of problem-solving for physics.	**1 2 3 4 5**

Appendix B

Physics End of Course Survey Questions

Here are a series of statements which may or may not describe your beliefs about this physics course. You are asked to rate each statement by circling a number between 1 and 5 where the numbers mean the following:

1: Strongly Disagree	2: Disagree	3: Neutral	4: Agree	5: Strongly Agree

Respond to the statements by circling the number that best expresses your feeling. Work quickly. Don't overelaborate the meaning of each statement. The statements are meant to be taken as straightforward and simple. If you don't understand a statement, leave a blank response. If you understand, but have no strong opinion, respond by placing a circle on 3.

1	To understand most of the basic ideas in this Physics course, I just read the textbook, work most of the problems, and/or pay close attention in class.	**1 2 3 4 5**
2	From a derivation or proof of a formula, I learn that the equation obtained is valid and that it is alright to use in solving Physics problems.	**1 2 3 4 5**
3	I read the Physics textbook in detail and work through many of the example problems given there.	**1 2 3 4 5**
4	In this Physics course, I do not expect to understand equations in an intuitive sense; the equations must just be taken as givens.	**1 2 3 4 5**
5	"Problem-solving" in Physics basically means matching problems with facts or equations and then substituting values to get a number.	**1 2 3 4 5**
6	The most crucial step in solving a Physics problem is finding the right equation to use.	**1 2 3 4 5**
7	In doing a Physics problem, if my calculation gives a result that differs significantly from what I expect, I'd have to trust the calculation.	**1 2 3 4 5**
8	The derivations or proofs of equations presented in class or the text have little to do with the solving problems skills I need to succeed in this Physics course.	**1 2 3 4 5**
9	The best way for me to learn Physics is by carefully analyzing a few problems in detail rather than by solving many problems.	**1 2 3 4 5**
10	If I don't remember a specific equation needed for a problem in an exam there's nothing much I can do to come up with it.	**1 2 3 4 5**
11	The main skill that I expect to get out of this Physics course is learning how to solve physics problems.	**1 2 3 4 5**
12	When I solve most exam or homework problems, I explicitly look for the concepts and patterns that underlie the problem.	**1 2 3 4 5**

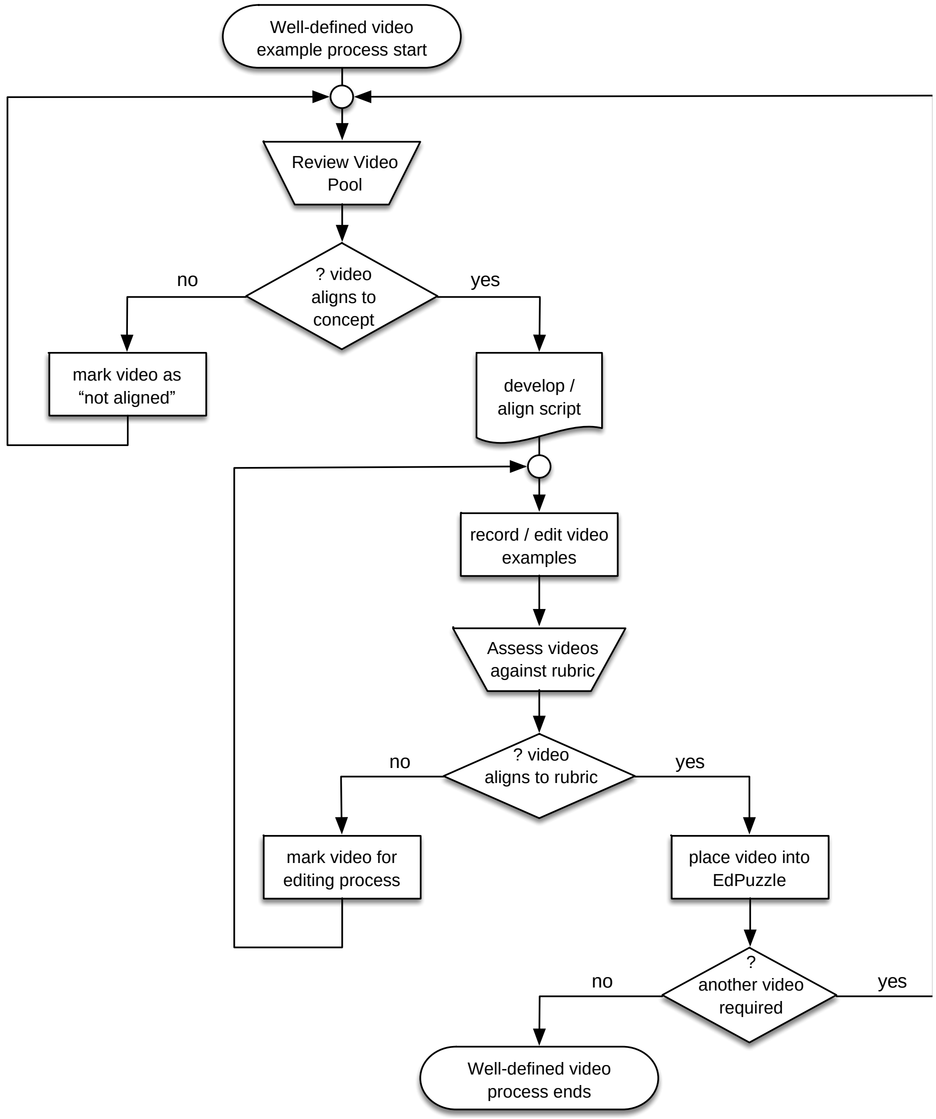
13	"Understanding" Physics problems basically means being able to recall something you've read or been shown.	**1 2 3 4 5**
14	Developing a mental picture and drawing it out helps in "understanding" Physics problems.	**1 2 3 4 5**
15	To be able to use an equation in a problem (particularly in a problem that I haven't seen before), I need to know more than what each term in the equation represents.	**1 2 3 4 5**
16	Learning problem-solving in Physics requires that I substantially rethink, restructure, and reorganize the information that I am given in class and/or in the text.	**1 2 3 4 5**
17	If I cannot make progress on a Physics problem that is different than the examples presented in class or the text, but similar in context, I look for an example that matches my particular problem online.	**1 2 3 4 5**
18	I prefer textual problem-solving examples to follow as the best way to understand other problems.	**1 2 3 4 5**
19	I prefer video problem-solving examples to follow as the best way to understand other problems.	**1 2 3 4 5**
20	My confidence increases when I watch videos that show methods of problem-solving for physics.	**1 2 3 4 5**

Appendix C

TABLE I.

	5	4	3	2	1	0	NA(problem)	NA(solver)
USEFUL DESCRIPTION	The description is useful, appropriate, and complete.	The description is useful but contains minor omissions or errors.	Parts of the description are not useful, missing, and/or contain errors.	Most of the description is not useful, missing, and/or contains errors.	The entire description is not useful and/or contains errors.	The solution does not include a description and it is necessary for this problem /solver.	A description is not necessary for this *problem*. (i.e., it is given in the problem statement)	A description is not necessary for this *solver*.
PHYSICS APPROACH	The physics approach is appropriate and complete.	The physics approach contains minor omissions or errors.	Some concepts and principles of the physics approach are missing and/or inappropriate.	Most of the physics approach is missing and/or inappropriate.	All of the chosen concepts and principles are inappropriate.	The solution does not indicate an approach, and it is necessary for this problem/ solver.	An explicit physics approach is not necessary for this *problem*. (i.e., it is given in the problem)	An explicit physics approach is not necessary for this *solver*.
SPECIFIC APPLICATION OF PHYSICS	The specific application of physics is appropriate and complete.	The specific application of physics contains minor omissions or errors.	Parts of the specific application of physics are missing and/or contain errors.	Most of the specific application of physics is missing and/or contains errors.	The entire specific application is inappropriate and/or contains errors.	The solution does not indicate an application of physics and it is necessary.	Specific application of physics is not necessary for this *problem*.	Specific application of physics is not necessary for this *solver*.
MATHEMATICAL PROCEDURES	The mathematical procedures are appropriate and complete.	Appropriate mathematical procedures are used with minor omissions or errors.	Parts of the mathematical procedures are missing and/or contain errors.	Most of the mathematical procedures are missing and/or contain errors.	All mathematical procedures are inappropriate and/or contain errors.	There is no evidence of mathematical procedures, and they are necessary.	Mathematical procedures are not necessary for this *problem* or are very simple.	Mathematical procedures are not necessary for this *solver*.
LOGICAL PROGRESSION	The entire problem solution is clear, focused, and logically connected.	The solution is clear and focused with minor inconsistencies	Parts of the solution are unclear, unfocused, and/ or inconsistent.	Most of the solution parts are unclear, unfocused, and/ or inconsistent.	The entire solution is unclear, unfocused, and/ or inconsistent.	There is no evidence of logical progression, and it is necessary.	Logical progression is not necessary for this *problem*. (i.e., one-step)	Logical progression is not necessary for this *solver*.

Appendix D


Well-defined video example process start
Review Video Pool
? video aligns to concept
no
yes
mark video as "not aligned"
develop / align script
record / edit video examples
Assess videos against rubric
? video aligns to rubric
no
yes
mark video for editing process
place video into EdPuzzle
? another video required
no
yes
Well-defined video process ends

Appendix E: Modified Physics Curriculum Lesson Outline

Unit: Heat and Thermodynamics

- Chapter 9: Heat
  - Section 1: Temperature and Thermal Equilibrium
    (11:43 video; 13 open-ended questions)
    - Defining Temperature – kinetic energy, forms of energy
      - Complete well-defined problems – temperature conversion (OneNote digital notebook activity)
    - Thermal Equilibrium – uniform temperature
      - Complete 2 – 3 well-defined practice problems (class activity)
        (OneNote digital notebook activity)
      - YouTube video exemplar: Equilibrium temperature in a calorimetry problem https://youtu.be/EWrXALn6sUQ
    - Thermal Expansion – linear and two-dimensional expansion
      YouTube video exemplars: Thermal linear expansion
      https://youtu.be/B_Jkyipn7RM |
      https://youtu.be/JGGGji2F8cE
      - PS exercise: linear expansion (OneNote digital notebook)
      - YouTube video exemplar: two-dimensional thermal expansion
        https://youtu.be/X-oVB4mLcAA |
        https://youtu.be/91Frm6iZ47w
      - PS exercise: two-dimensional thermal expansion (OneNote digital notebook)
    - Measuring Temperature – Why are multiple temperature scales needed?
      - Scale names and parameters
      - Conversions between scales
      - Applications in the scientific and practical world
    - Ch. 9-1 Formative Quiz
      (Forms digital online format)
  - Section 2: Defining Heat
    (16:36 video; 12 open-ended questions)
    - Heat and Energy – temperature is a measure of heat; thermal units
    - Thermal Conduction – convection, conduction, radiation
      - Enrichment:
        YouTube video exemplar: https://youtu.be/Y-8OiK0p9gw
    - Conservation of Energy – potential, kinetic, internal energies
      - Sample Problem (Joule's Apparatus)
    - YouTube video exemplar: https://youtu.be/zd-FjMksimw
    - PS exercise: ill-defined problem – kinetic to heat energy conduction (OneNote digital notebook)
    - Ch. 9-2 Formative Quiz
      (Forms digital online format)

- Section 3: Changes in Temperature and Phase
  (12:55 video; 11 open-ended questions)
  - Specific Heat Capacity – mathematical relationship of heat, mass, and temperature of interaction of materials
  - Calorimetry – a method of measurement using conservation of energy
    - Sample Problem – find the heat of a substance prior to thermal equilibrium
    - YouTube video exemplar: https://youtu.be/uL0S0HBznNo
    - PS exercise: well-defined problem – calorimetry problem (OneNote digital notebook)
    - PS exercise: ill-defined problem – water heater problem
  - Latent Heat – phase changes in matter and internal energy changes
    - Definitions of heat of fusion and heat of vaporization
    - YouTube video exemplar: https://youtu.be/XWoPJN6zF2k
    - PS exercise: textbook problem; peer assessed in class
    - PS exercise: ill-defined problem – saving the freezing orange crop
- Standards based assessment activity

- Chapter 10: Thermodynamics
  - Section 1: Relationship Between Heat and Work
    (12:54 video; 10 open-ended questions)
    - Heat, Work, and Internal Energy
      - Demo of temperature difference engine
      - Define terms: system and environment
      - Explore the relationship between work, pressure and volume and how a gases' expansion and compression are important elements
    - Thermodynamic Processes
      - Define and contrast isovolumetric, isothermal and adiabatic processes
      - Explore common animated examples of these processes
    - YouTube video exemplars:
      - https://youtu.be/oOLO2Le3Yac | isovolumetric
      - https://youtu.be/KomRku3oQus | isothermal
      - https://youtu.be/hunmkRGBvBM | adibatic
    - Compute the work done during a thermodynamic process
      - Ill-defined problem: Calculating the energy of Titanic's steam engines from provided specification. (OneNote digital notebook)
  - Section 2: 1st Law of Thermodynamics
    (18:38 video; 9 open-ended questions; 5 MC)
    - Energy Conservation

            - Sample Problem – describes the relationship between work, internal energy, and heat in thermodynamics
            - YouTube video exemplar: https://youtu.be/AsjLI3g9feU
            - PS exercises: Complete 3 well-defined practice problems
        - Cyclic Processes – 4 stroke engine cycle; refrigeration cycle
            - Show the net change of internal energy is zero for cyclic processes
            - Diagram and label a thermodynamic cyclic process
    - Section 3: 2nd Law of Thermodynamics
      (25-minute video; The Mechanical Universe series; 10 open-ended questions)
        - Efficiency of Heat Engines – Carnot Engines
            - Demo of Stirling Engine in class
            - Explore the mathematical relationship of work extracted from the heat in an engine
            - Sample Problem – calculation of heat engine efficiency
            - YouTube video exemplar: https://youtu.be/3HpJMwhRDD8
        - Entropy – randomness in the universe; disorder of a system
            - Energy change in the cooling and freeing of water
        - Ch. 10 Formative Quiz – comprehensive
          (Forms digital online format)

- Unit Exam: Heat and Thermodynamics

Unit: Electrostatics

- Chapter 16: Electrical Forces and Fields
    - Section 1: Electric Charge
      (PowerPoint presented in class; no video)
        - Properties of Electric Charge – terminology; Millikan Experiment
        - Transfer of Electric Charge – conductors and insulators; induction charging
    - Section 2: Electric Forces
        - Coulomb's Law – mathematical relationship between electric force, electric charges and distance.
            - Introduction of Coulomb's proportionality constant
            - YouTube video exemplars: – electric force between linear charges https://youtu.be/-jxX7Vt2wrA | https://youtu.be/6XR8eHzpwyc
            - PS exercises: well-defined type: 3 basic Coulomb's Law problems
            - PS exercise: ill-defined type: find the charge on a linear separation of subatomic particles in hydrogen atoms
        - Sample Problem – application of the superposition principle to three-point charges interacting with each other

- Coulomb force is a field force
- Vectors and resultants in the x- and y-axis
- YouTube video exemplar: non-linear electric force calculations https://youtu.be/_ZuroDbIi8A
- PS exercise: well-defined type: electric force among four-point charges in a geometric square
- PS exercise – ill-defined type: three charged objects hanging on strings show a separation by repulsion (OneNote digital notebook)

- Section 3: The Electric Field
  ((25-minute video; The Mechanical Universe series; 12 open-ended questions)
  - Electric Field Strength
    - Define an electric field and its SI unit
    - Define direction of electric field with reference to test charge
  - Sample Problem – apply mathematic relationship with problem variables
    - The charge creating the electric field
    - The distance between the charge and test charge
  - YouTube video exemplar:
    - https://youtu.be/aLNOOyp2cZ0 | General solution exemplar https://youtu.be/JYLLCyN6hd0 | Linear charge problem exemplar
  - PS exercise – well-defined type: average electric field between hydrogen's proton and electron (OneNote digital notebook)
  - Sample Problem - Electric Field due to non-linear arrangement of charges
    - Use the superposition principle and x-axis and y-axis fields
    - Find the resultant field using Pythagorean theorem and trigonometric functions
    - PS exercise – well-defined type: electric field at a point with three non-linear charges
  - Ch. 16 Concept Review questions (homework assignment)
  - YouTube video exemplar:
    - https://youtu.be/m5Ff6ajRP4M | Electric field of equilateral triangle with different charges
    - Ill-defined problem – Electric Field problems
      - Four pre-selected problems from textbook curriculum
      - Solutions done in OneNote digital notebooks
      - Video created from playback of the animated handwritten OneNote solutions
      - Video contains student voice recording along with the handwritten animation playback
      - Video target length 4 to 5 minutes

                - Diagramming Electric Field Lines
                    - Number of lines is proportional to field strength
                    - Field lines are tangent to field vector at any point (curved lines)
                - Conductors in Electrostatics - identify the 4 properties of conductors at electrostatic equilibrium

- Chapter 17: Electric Energy and Current
    - Section 1: Electric Potential
      (13:37 video; 15 open-ended questions)
        - Electric Potential Energy – definition; relationship to mechanical energy
        - Mathematical relationship between charge, electric field, and distance
        - Potential Difference
            - contrast electric potential energy and potential difference
            - describe 2 methods potential difference can be calculated
        - YouTube video exemplars: Electric Potential Energy & Difference
            - https://youtu.be/eZPmIKneSBk | well-defined type example
            - https://youtu.be/z-4monRooN4 | ill-define type example
        - PS exercises: (3) well-defined problems as a classroom activity
        - Sample Problem – potential difference
            - Superposition Principal applied to potential difference
                - Potential difference due to multiple charges
                - Potential differences are scalars – calculations of potential difference are simply additive
        - Assignment: Textbook formative assessment at end of section
    - Section 2: Capacitance
      (10:22 video; 13 open-ended questions)
        - Capacitors and Charge Storage – definition; lighting a bulb with a capacitor demo
            - Explore the relationship between charge and potential difference
            - Explore the component relationships in a parallel plate capacitor: plate surface area, plate separation distance, permittivity of dielectric between plates
        - Energy and Capacitance
            - explore the mathematical relationship of potential energy storage in a capacitor as it depends on charge and potential difference between plates
            - Read a real-world application of capacitance – a laptop keyboard
        - Sample Problem – determine the potential energy in a capacitor
        - YouTube video exemplars:

        - https://youtu.be/CFzCDg9yp7Q | Charge, voltage, capacitance
        - https://youtu.be/Vu25UCkmjGU | Energy stored by a capacitor
    - PS exercises: (2 – 3) well-defined problems as a classroom activity
  - Section 3: Current and Resistance (no video)
    - Electric Current: definition; mathematical relationship of current to charge and time; SI unit label
    - Student lab activity: measuring current in a simple DC circuit (use both analog and digital meters)
    - Drift current: definition and diagram analysis
      - YouTube video exemplar: Drift Current
        - https://youtu.be/__n0URvcymA
    - Electric resistance definition; mathematical relationship of resistance, potential difference and electric current
      - YouTube video exemplar: Ohm's Law
        - https://youtu.be/euVoSumiNk8
    - PS exercises: well-defined practice problems – two current problems and two resistance problems
    - Student lab activity:
      - Find the value (in ohms) of a resistor's labeled
      - Compare the measured value of resistance to its label value
      - Does the percentage error fall within the labeled tolerance?
    - Student lab activity:
      - Complete several DC series circuits with resistors and light bulbs.
      - Measure and compare electric current, potential difference in the circuits
    - Enrichment activity: Resistance in series and parallel circuits
      - YouTube video exemplar: https://youtu.be/GcQeEXYXpww
      - Build and measure electric current, potential difference and resistance in a circuit with parallel resistors.
  - Section 4: Electric Power (no video)
    - Direct current vs alternating current – historical reasons
    - Energy transfer example – chemical battery to light bulb
    - Explore the relationship between electric power, potential energy, charge, potential difference, and time
    - Sample Problem – Electric Space Heater problem
    - YouTube video exemplar:
      - https://youtu.be/fQGjzxNY_mY | Power in a series circuit

- Unit Exam: Electrostatics