THE INTEGRATION OF ENGINEERING DESIGN PROJECTS INTO THE SECONDARY SCIENCE CLASSROOM

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A THESIS

Submitted to
Michigan State University
In partial fulfillment of the requirements
For the degree of

MASTER OF SCIENCE

Physical Science - Interdepartmental

2012

ABSTRACT

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In order to compete in the global economy, the United States needs to adequately train an increasing number of students in the STEM (Science, Technology, Engineering, and Mathematics) fields. Recent studies show that the U.S. is lagging behind other countries in international science and mathematics assessments, and that the motivation of students to enter into and stay in the STEM fields of study is low. Businesses and government alike are pushing for increased instruction in science and math for K-12 students as a means for producing larger numbers of STEM ready students. New approaches to adding more engineering instruction into the curriculum are being applied but current research into the effectiveness of such approaches is mixed. This study sought to gauge the effectiveness that integrating engineering design projects into the traditional physical science classroom has on students understanding of the applied scientific concepts as opposed to traditional instruction. The results indicate that integration of engineering design projects has a positive effect on student's science concept knowledge as well as their motivation in the classroom.

Table of Contents

List of Tables

List of Figures

Introduction

The trend in STEM education

The United States' success in the global marketplace will depend on the skills of its population, and as the world becomes increasingly technological, the skills that will be of the greatest benefit will be those in the STEM (Science, Technology, Engineering, and Mathematics) topics. Frighteningly, recent International comparisons of student performance in science and mathematics consistently place the US in the middle of the pack or lower (The President's Council of Advisors on Science and Technology, 2011). There is also a startling lack of interest by students to enter the STEM fields, particularly among women and minorities, with interest in pursuing STEM related fields peaking at the middle school level (Brophy, et al, 2008).

Even among college students who choose a STEM field as a major there is an alarming percentage of students who do not remain on this path of study. Seymour (2000) cites a 1993 report from UCLA that indicates that of students who select a STEM major, 40% will switch majors largely in the first 2.5 years of undergraduate work. Among the highest achieving students the problem is even more pronounced. In Seymour's study approximately half of the STEM students with an SAT score above 650 subsequently switched to a non STEM major. Interviews conducted during the study show that 40% of the switchers cited inadequate high school science and mathematics preparation (ibid).

Faced with the precarious situation of fading US supply of STEM ready workers, particularly engineers, and increased competition from well educated and lower paid foreign talent, business leaders and government alike have urged for a commitment to producing workers skilled in the STEM fields (Ed Week, 2008). As a result many states have responded by increasing the graduation requirements, particularly in science and math. In the years from 1989 to 2006, The national average number of required science and math courses increased by almost a full course, from 2.0 to 2.7 for science and 2.2 to 3 for math (Cavanagh, 2008). However, it is not clear whether increasing graduation requirements alone will meet the goal of increasing the number of and achievement of engineers that enter the workforce. In his paper *STEM Education: Proceed with Caution,* Williams (2011) argues that if the goal of curriculum reform is economically driven, than an integrated approach to STEM education that incorporates engineering and technology is key.

Incorporating Engineering into the K-12 Curriculum

Stand Alone Engineering Courses

With the increased emphasis on STEM education, the best approach to incorporating engineering into the curriculum is still being investigated. While most stand alone K-12 engineering courses align with national science standards (Kimmel & Rockland, 2002) and are successful in introducing students to engineering and design principles not found in the traditional science or math course, these topics are often underrepresented or missing from traditional standardized measures of student achievement in science and mathematics, particularly the ACT, SAT, and NAEP.

One of the most widely implemented engineering curriculums in the US is administered by Project Lead the Way (PLTW), a company headquartered in Indianapolis, Indiana, that trains high school and middle school teachers to deliver their proprietary curriculum. This curriculum, targeted to grades 6-12, includes courses in computer aided design, mechanical, electronic, aeronautical, civil, and biomedical engineering. These courses are rigorous in nature and offer students the chance at college credit for each course for which they can successfully pass an end of course exam. While personally teaching several of these courses I have witnessed an incredible level of student effort and understanding of the engineering principles involved, with many of the students earning college credit and going on to further studies in the engineering and technology fields. However, in a 2010 study by Natalie Tran and Mitchell Nathan, students who took PLTW courses showed no increase in science and mathematics standardized test scores when compared to their peers who did not take the PLTW courses. It has been suggested that improving the focus on math and science in these courses by incorporating it more readily (Dugger,1993) and/or altering the standardized methods of testing student achievement to more accurately reflect engineering content would improve student performance on these tests (Kelley & Wicklein, 2009).

Integrated Engineering Projects/Modules

Another approach to incorporating engineering into the K-12 curriculum involves integrating engineering projects or modules into a science or mathematics course. Integration of engineering projects into the science and mathematics classroom incorporates imaginative views of technology and society and engages students to apply the science they have learned thus making for "good science education" (Carlsen, 1996). Integration of engineering principles into existing courses compared to stand alone courses has also been shown to result in improvements in the science and mathematics background of students (Fadali & Robinson, 2000) due to the increased focus on the science and mathematics aspects of the courses in which they are integrated. In a 2006 study, Cantrell, et al showed a larger increase in standardized test scores in math and science for students enrolled in an integrated science and engineering course when compared to their peers in a non-integrated course.

The integrated approach also allows for the early exposure of engineering, its culture, and its processes to students, which is important to developing skills in STEM education (Bordagna, et al, 2010). Furthermore, students who have completed integrated engineering modules embedded in standard courses have remarked that their conceptual understanding of the module concepts and their inquiry skills have increased in depth. In addition these students have shown to be highly motivated to investigate concepts and relationships that they may otherwise not have done in a traditional classroom (Taylor, et al, 1999).

Although not widely implemented, there is evidence of success of the integrated approach. One such school that has implemented this approach is Baltimore Polytechnic, a magnet school in Maryland that used an integrated biotechnology engineering curriculum. In recent state standardized tests the school had a 93.4% passing rate on the biology portion, showing that the integrated approach can induce significant results when compared to a traditional, non-integrated curriculum. The school has also had three top ten finishers at the prestigious Intel Science Talent Search contest (Trotter, 2008a). It must be noted however that, as a magnet school, admissions requirements are robust and the school draws mainly from a high achieving student population.

Conclusions of Stand Alone vs. Integrated Engineering Curricula

As cited previously, the main goals of overhauling STEM education in the US have been to produce more engineering and technology ready workers by increasing student understanding of and enthusiasm in STEM fields, while at the same time increasing student achievement on standardized measurements of science and mathematics knowledge. With these goals in mind, evidence shows that an integrated approach to STEM education would be better suited for both introducing and exciting students in engineering and technology fields, while at the same time elevating standardized test scores in science and mathematics.

An integrated model for teaching engineering principles is also favorable, in terms of cost and logistics, when compared to the stand-alone model. Stand alone curricula, such as PLTW, require a large upfront investment in equipment, teacher training, room considerations, etc – and continued costs in computer software licenses, computer upkeep, scheduling conflict, teacher salary, etc. In contrast, an integrated approach uses existing teachers, classrooms, and, depending upon the level of sophistication of the engineering projects/modules, incurs little supply costs. On the whole an integrated model would allow for quick and widespread implementation, while still meeting the outlined goals of the STEM education movement.

Integration as Problem Based Learning (PBL)

The primary difference between traditional classroom instructional strategies and a model which integrates engineering design principles into existing courses is the use of problem based learning strategies. Problem based learning is summarized by Hmelo-Silver (2004):

> Problem-based approaches to learning have a long history of advocating experience-based education. Psychological research and theory suggests that by having students learn through the experience of solving problems, they can learn both content and thinking strategies. Problem-based learning (PBL) is an instructional method in which students learn through facilitated problem solving. In PBL, student learning centers on a complex problem that does not have a single correct answer. Students work in collaborative groups to identify what they need to learn in order to solve a problem. They engage in self-directed learning (SDL)

> and then apply their new knowledge to the problem and reflect on what they learned and the effectiveness of the strategies employed. The teacher acts to facilitate the learning process rather than to provide knowledge. The goals of PBL include helping students develop 1) flexible knowledge, 2) effective problem-solving skills, 3) SDL skills, 4) effective collaboration skills, and 5) intrinsic motivation.

By integrating problem based learning, Hmelo-Silver states that not only do students become more independent self directed learners and improve their problem solving skills, but they also more readily learn the content of the course in which PBL strategies are employed.

In a problem based model, students become responsible for their own first exposure to the material through reading, note taking, and doing assigned example problems as a prerequisite for success (Jones-Wilson, 2005), thus making them more self directed. Furthermore, students making decisions and communicating during the problem based learning approach leads to better retention of the course material (Roscoe, 2004). If the design of the problem based, integrated project or module connects the material being taught to a real world, student relatable context, retention is even further enhanced (Avery & Kassam, 2011).

Study

The goal of this study was to ascertain whether the incorporation of engineering design projects/modules into a physical science course increases student understanding of the specific scientific concepts used during the project. The hypothesis was that by incorporating engineering design into a physical science course, students will show a statistically significant gain in their understanding of the course content as measured by assessments developed for this study, and show enthusiasm and effort during class.

The impetus for conducting this study surfaced during PLTW courses that I have taught over the past few years. I have noted that during these courses, which are stand alone engineering curricula, students that were otherwise not successful in math and science, became much more motivated and the quality of work they submitted, as well as their grasp of the science and math concepts, greatly increased. Many of the students who have taken the courses have also decided on pursuing STEM fields, particularly engineering, as a career choice.

The purpose of this study is to test the outcomes of using integrated engineering design projects/modules to improve student achievement. However, unlike the majority of studies done on this topic, which use standardized test data to establish student gains, unit specific tests were developed for this study. This approach was employed to establish if engineering design projects and principles that allow students to apply the science learned in each unit are of value as a science teaching tool or even as a replacement for traditional methods of instruction.

Demographics

This study was conducted during the 2011-2012 school year at Hanover Horton High School in Horton, Michigan, a rural district Southwest of Jackson, Michigan. As per the latest count information (2011), the High School has 435 students from grade 9 through 12. With the schools proximity to several lakes, while at the same time being situated in a rural area, the socio economic status (SEC) of our students ranges wildly. The rate of students receiving free or reduced lunch, a relevant indicator of student body SEC, is at 27.1%.

The district is homogenous, with a population that is 93.6% white, 3.2% Hispanic or Latino, 1.6% multiracial, 0.7% Indian or Alaskan native, 0.4% black or African American, and 0.2% Asian.

The participating students were primarily freshman enrolled in four sections of the 9^{th} grade physical science course, all of which were taught by the author. Of the 122 students that were enrolled in physical science, 65 returned the consent form (Appendix E) indicating their participation in the study.

Implementation

Overview

To conduct this study, engineering design projects/modules were integrated into four 9^{th} grade physical science units at the completion of traditional instruction. The units used, and their corresponding engineering project/module, are shown in Table 1:

Table1: Units of Instruction with the Corresponding Engineering Design Projects

Unit of Instruction	**Engineering Design Project**
Matter: Mixtures vs Pure Substances	Design and Build a Water Filter
Motion: Velocity, Acceleration, and Forces	Egg Drop Device
Forces: Forces, Net Force, and Friction	Note Card Car
Energy: Heat and Thermodynamics	Design a Coffee Mug

During the course of the study, traditional classroom instruction was implemented with a combination of reading, lecture, note taking, data collection and analysis labs, and periodic testing and quizzing, with the integrated engineering design projects serving as the culminating activity in four distinct units (Table 1). The engineering design projects required the review, application, and analysis of scientific concepts covered during the unit while introducing engineering design principles (see page 14 - 15). During projects, no new scientific concepts were covered and teacher assistance pertaining to the scientific concepts was instigated by the students.

The projects were completed as a group ranging from two students to five students, depending on the particular project. While in groups each student had particular responsibilities which were assigned by the group. Each project began with a review of the pertinent concepts, as well as an introduction to new terminology, any constraints for the project, and an overview of the goals of the project. During the project students were required to identify how, and justify why, they applied the scientific concepts learned during the unit.

Student growth was measured using identical pre and post tests (Appendices F through I) that covered the main scientific concepts that were to be employed during each project. The pre and post tests were structured in a way similar to that of their traditional physical science assessments and were comprised of a mixture of true/false, multiple choice, and essay questions. The pre test was administered immediately following the conclusion of traditional instruction of the unit and immediately before the engineering design project, with the post test being administered immediately following the completion of the project.

Engineering Design Principles

The projects found in this study require students to use engineering design principles not used in traditional science instruction. These engineering design principles, when implemented, are referred to as the engineering design process. The engineering design process is a systematic approach to solving problems. The engineering design process is comprised of the following:

- Define the Problem and Gather Information
- Two and Three Dimensional Sketching Strategies
- Brainstorm Individually and with Groups
- Identify Criteria and Constraints
    - Mass
    - Size
    - Equipment
    - Supplies
    - Time
    - Performance
- Explore Alternate Ideas
- Select an Approach Using Group Consensus
- Make and/or Model Prototypes
- Test and Evaluate the Design using Specifications
- Refine the Solution
- Communicate Processes and Results

The Projects

1) Design and Build a Water Filter Project

The *Design and Build a Water Filter Project* required students to apply the scientific concepts of the instructional unit pertaining to Matter. These include:

- Classifying Matter
- Mixtures vs. Pure Substances
- Types of Mixtures
    - Homogeneous
    - Heterogeneous
- Relative sizes of Particles
- Physical and Chemical Properties of Matter
- Physical and Chemical Changes of Matter
- Separation of Substances using Physical and Chemical Properties
- Dissolution

At the beginning of the project (Appendix A), students were introduced to common contaminants found in water, as well as types of filters used to remove specific contaminants based on size. Students, working in a group of five, were tasked with assigning and researching a particular step in the water filtration process, which included: Aeration, Flocculation, Filtration, and Disinfection. The fifth student in the group was assigned as a project manager and supervised the construction of the filter and development of a procedure to be used in the water purification process. Students then constructed their filter (see Figure 1 for an example) using the provided supplies.

Figure 1: A completed water filter. (For interpretation of the references to color in this and all other figures, the reader is referred to the electronic version of this thesis.

After constructing their filter, students carried out their purification procedure using surface water from a local marsh, recording down observations of the water during each step of their procedure. Upon completion of their observations students answered several reflection questions, relating their observations to the science content.

2) Egg Drop Project

The *Egg Drop Project* required students to apply the scientific concepts of the instructional unit pertaining to Motion and Forces. These include:

- Motion
- Speed and Velocity
- Acceleration
- Forces
- Collisions

At the beginning of the project (Appendix B), the instructor reviewed causes of forces in a collision and methods for controlling the variables which influence the amount of force exerted during a collision, mainly initial velocity and the time over which a collision takes place. Students, working in groups of 2 or 3, were instructed to design and build a device in which an egg can be placed and would survive a fall from 2 meters. Students were allowed a set of materials (Appendix B), and were constrained as to the weight of the container. A complete schematic of the design had to be presented and approved by the instructor before construction took place. Upon completion, students tested their device (see Figure 2 and Figure 3 for examples). Immediately following testing, students completed a design feature sheet and answered post testing questions which related the science concepts from the unit to their specific design.

Figure 2: A completed Egg Drop Device being tested with a plastic demo egg

Figure 3: An Egg Drop Device being tested

3) Note Card Car Project

The *Note Card Car Project* required students to apply the scientific concepts of the instructional unit pertaining to Forces. These include:

- Forces
- Friction and air resistance
- Inertia
- Momentum

At the beginning of the Project (Appendix C), the instructor reviewed transfer of momentum between objects in contact, frictional forces acting on objects in motion, and strategies for reducing the frictional forces. Students, working in groups of two, designed and built a "car" (see Figure 4 for example) out of a piece of 3 x 5 inch note card that would capture a marble that was rolled down an incline (see Figure 5), and be carried down the hallway as far as possible (see Figure 6 for example). The “car” could be of any size, shape, or mass but could not be made of any other material other than the note card. Students were required to draw schematics of several designs, build several prototypes, test these prototypes, and select and test a final design. Immediately following testing, students completed a design feature sheet and answered post testing questions (Appendix C) which related the science concepts from the unit to their specific design.

Figure 4: A completed note card car

Figure 5: A marble being rolled down an incline composed of a ruler connected to several textbooks. A note card car is resting at the bottom of the incline waiting for the marble to be released.

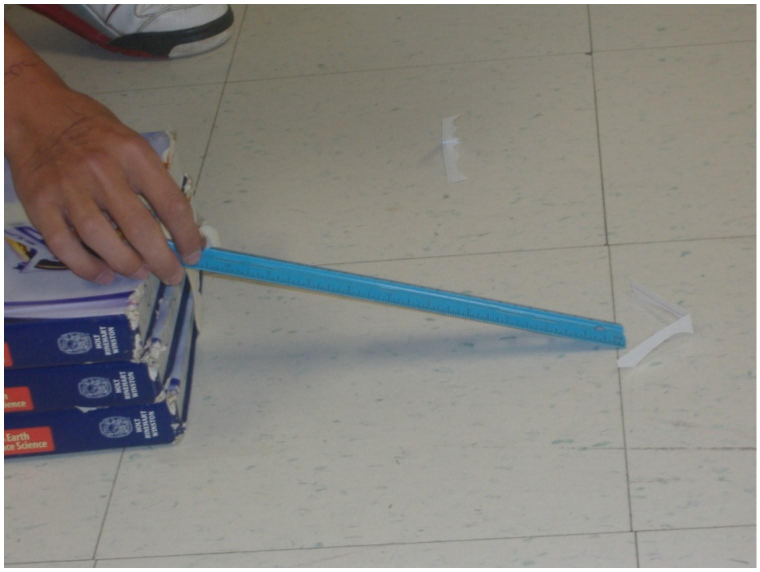


Figure 6: A note card car being tested showing the extent that the car travelled. The car is marked.

4) Mug Design Project

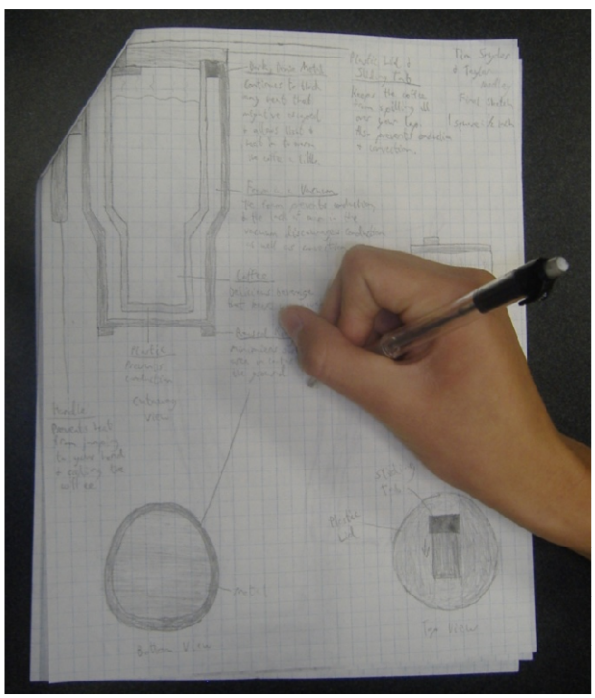
The *Mug Design Project* required students to apply the scientific concepts of the instructional unit pertaining to Thermodynamics. These include:

- Laws of Thermodynamics
- Heat
- Heat Transfers
    - Conduction
    - Convection
    - Radiation
- Conductors and Insulators
- Temperature

At the beginning of the project (Appendix D), the instructor reviewed methods of heat transfer and material properties that make substances effective conductors or insulators. Students, working in groups of two, were then instructed to design a coffee mug that would keep coffee at a high temperature for as long as possible. Students were presented with example mugs to analyze and use as a basis for their design (Figure 7). Students submitted a full annotated sectional schematic of their design, including descriptions as to how their design prevented heat transfer (see Figure 8 for example).

Figure 7: A student examining example coffee mugs.

Figure 8: An annotated schematic of a student designed coffee mug



Results

Pre and post test results for each project were averaged for all students who completed both the pre and post tests, as well as a combined pre and post test average (Table 2) which was created by adding the pre and post test scores of each student that had completed all pre and post tests and averaging their combined scores.

Table 2: Average pre and post test scores for all students, including p values

Image Premission	Filter Pre test	Filter Post Test	Egg Drop Pre Test	Egg Drop Post Test	Notecard Car Pre Test	Notecard Car Post Test	Mug Design Pre Test	Mug Design Post Test	Combined Pre Tests	Combined Post Test
AVE	6.58	6.95	5.75	6.14	5.74	6.09	5.56	6.11	23.87	25.42
n	64		59		57		57		54	
p values	0.057		0.026		0.072		0.006		0.001	

All projects showed an increase in student scores, however results of a paired, single tailed T Test show that statistically significant gains ($p<.05$) were achieved only during the Egg Drop and Mug Design Projects. The combined scores also showed a statistically significant improvement.

An analysis comparing the pre and post test results of the percentage of students that showed growth, maintained their score, or decreased their scores was also completed (Table 3). The average percent improvement from the pre to the post tests by students with increased scores, and percent decline from the pre to post tests by students with decreased scores is shown in Table 4.

Table 3: Analysis of the percentage of students showing increased scores, maintained scores, and decreased scores from pre to post test.

	Filter Project	Egg Drop Project	Notecard Car Project	Mug Design Project	Combined Project Scores
# of Students Tested	65	59	57	57	54
% of students with increased scores	46.15	47.46	40.35	42.11	64.81
% of students who maintained scores	23.08	30.51	33.33	36.84	11.11
% of students with decreased scores	30.77	22.03	26.32	21.05	24.07

Table 4: Average percent increase or decrease by students on the pre to post tests.

	Filter Project	Egg Drop Project	Notecard Car Project	Mug design Project	Combined Scores
Average % improvement for students with increased scores	20.00	16.43	20.00	20.00	8.08
n with increased scores	30	28	23	24	35
Average % decline for students with decreased scores	15.45	18.46	17.33	13.33	6.38
n with decreased scores	20	13	15	12	13

Conclusion

Upon review of the data, the initial hypothesis, that incorporating engineering design projects will show an increase in knowledge of science concepts, appears to be supported. As shown in Table 2, students showed statistically significant gains from the pre to post tests in two of the four projects, with the remaining two slightly missing the burden of being statistically significant (Filter Project at $p = .057$, and the Note Card Car Project at $p = .072$). While the effectiveness of specific engineering design projects as a tool for teaching science can vary, the combined scores, which would more accurately reflect the effectiveness of engineering design projects as a whole, showed a statistically significant ($p =.001$) 6.49% increase in scores from the pre test to the post test. The very low p value of .001 for the combined scores is striking as the p values for the individual projects range from .006 to .072. Analysis of individual students' results help to explain this occurrence. As shown in Table 4, students who improved their scores from the pre test to the post test outnumbered students who showed a decrease by approximately a 2 to 1 ratio in all of the projects, and the students who did increase their scores showed a larger percentage change in scores when compared to the students who showed a percent decrease with the exception of the egg drop project.

Closer analysis of individual students' pre and post test scores showed a startling occurrence. Even though a statistically significant gain was shown on the student's combined pre and post test scores on average, 35.17% of students either maintained or decreased their scores from the pre test to the post test (Table 3). This would indicate that a large portion of the students had difficulty with connecting the science content to the engineering design projects. Also, 64.81% of students showed an overall improvement of their combined scores from the pre to post test with an average increase of 8.08%, but among the 24.07% of students that showed a decrease in scores the average decrease was 6.38% (Table 3 & Table 4). This would indicate that while most students increased their understanding of the science concepts being used by a noticeable amount, there was a minority of students that showed decreases in their understanding.

Analysis of the percent change in scores also revealed another interesting occurance. The average increase (8.08%) and average decrease (6.38%) values for the combined scores shown in Table 4 tended to be much lower than these values for the individual projects which ranged from 13.33% to 20.00%. This can be explained by two factors: many of the students who maintained their scores from pre to post testing for many of the individual projects ended up with an overall increase in combined scores, lowering the average increase, and that few of the students decreased their scores from pre test to post test for all projects, lowering the overall decrease in the combined scores.

The inability for some students to make connections between the engineering design projects and the science content could be explained by the use of group projects which have a tendency to produce “social loafing” (Bacon, 2005), the occurrence of students free riding on the achievement of others in their group. Another common problem with group projects is that it tends to produce specialization of tasks for students within the group (Bacon, 2005), which can decrease the overall understanding of the concepts involved when compared to individual work in which the students are responsible for all facets of the project. Observations made by the instructor during the projects shows evidence of social loafing and specialization, an example of this is when students were completing the egg drop project, one student designated himself the “tape cutter” for the group. This student’s self appointed job consisted of only cutting the duct tape needed for the project to lengths specified by the other members of their group. Outside of this job the student played little part in the design and analysis of the egg drop device, drastically reducing their understanding as to what or how their group was proceeding with the project and its goals. In contrast to this, some students would take it upon themselves to be the group leader and would be intimately involved with the entire design, build, and testing of the egg drop device. When the instructor would question groups about their progress of their projects, it was often the group leaders who would answer all of the questions, while the students with a narrower focus, such as the self appointed "tape cutter" would defer to the others in the group.

Student Motivation

During the projects it was observed by the instructor that students seemed much more engaged when completing their projects when compared to traditional instruction. Off task behavior, inter group talking, and behavioral problems were almost nonexistent during the projects. Communication between group members revolved almost entirely around the task at hand, and communication between groups was often aimed at constructive feedback about designs. Students overwhelmingly reported enjoying the projects, particularly the control they had over their design and implementation of the given task. This level of motivation is consistent with the observations of the instructor's project based PLTW engineering courses.

Intrinsic motivation among students has been shown to greatly increase test scores and student understanding (Patrick 2007, Blackwell 2007) but motivating students is a constant struggle for all secondary teachers, and what may be motivating to some students may not be motivating to others. It is therefore important to investigate the almost universally increased motivation of students when completing the engineering design projects in this study, and attempt to replicate it in other aspects of classroom instruction. A 2011 study by Clarice Wirkala on the use of problem based learning concludes,

> …the sequence of goal-oriented, inquiry-like activities (asking questions, identifying learning gaps, finding evidence, revising explanations, etc.) may serve as an effective scaffold that heightens young students' cognitive and affective engagement. Moreover, the problems are authentic; students recognize them as important and worth thinking about and recognize that they could apply to their lives outside of school, all of which may increase motivation.

Wirkala's study implies that goal oriented and self directed inquiry activities, such as the engineering design projects used in this study, increases the students' engagement with the concepts being applied. Also, by providing students with a problem that they can recognize as applying to their lives outside of school, such as with engineering design projects, motivation is increased.

Therefore, the effectiveness of the engineering design projects can most likely be linked to the ability they have to intrinsically motivate students, and students tend to be more motivated when they believe that the outcome of learning is under their control (Hmelo-Silver, 2004).

Final Analysis

Engineering design projects are a valid teaching tool in their own right by increasing motivation and creativity, introducing students to engineering design principles, teaching students how to apply learned content, improving problem solving skills, and improving group communication skills. The focus of this study, however, was to gauge the effectiveness that engineering design projects have on students' knowledge of science content. While the study did show an increase in students' science content knowledge as per the pre and post tests, relatively small gains were shown for the extended time needed for the projects. Therefore, if the only goal of integrating engineering projects into the science classroom is to increase science content knowledge in the students, then the time spent on the projects must be weighed against the time that could have been spent introducing new concepts or delving in deeper into the existing curriculum. However, the goal of instruction should not be only to teach the curriculum, but also to create well rounded and motivated learners capable of applying the learned content. In this regard the integration of engineering design projects should be viewed as a valuable option within the science classroom and will continue to be expanded in the instructor of this study's classroom.

One of the main advantages, outside of student achievement, that the engineering design projects offered was a change of pace from traditional classroom instruction for the students. They were allowed to be in charge of their own education during the projects instead of relying on information from the instructor, this resulted in a renewed enthusiasm and increased motivation towards their education which could potentially carry over into other STEM courses. It is this model of education which makes the PLTW engineering classes so successful and led to the undertaking of this study. During the instructors PLTW courses, which by their nature are project based, it was not unusual to see students entering class early, leaving late, and staying for many hours after school in order to refine their designs and prototypes.

A less intrusive and time consuming option from that of the stand alone engineering course (PLTW) and the integrated engineering design approach used in this study, motivation of students could be increased by completing smaller activities or projects which replicate that which makes the engineering design projects so successful, problem based and student led learning. The focus of such projects could be adapted more towards the science content and less on the engineering design aspects as needed based on the topics being addressed and the level of comfort an instructor has with engineering principles.

Issues Pertaining to the Implementation of the Study

Frequent Pre and Post Testing

This study was conducted as four separate engineering design projects integrated throughout the year, and as such, included pre and post testing before and after each project respectively, for a total of eight assessments. The constant use of classtime for these pre and post tests led to a significant amount of student fatigue, as these assessments were in addition to their normal classroom assessments such as tests and quizzes. Often times the students would ask whether or not the pre and post tests were worth points towards their final grade. These questions often represent a desire by the students to “blow them off” and not put forth their full effort, which could affect the reliability of such assessments. A possible solution to student fatigue could be to provide one cumulative pre and post test, but the amount of time between projects could result in inaccurate data as retention of material is difficult over such extended periods.

Pre and Post Test Reliability

The pre and post tests used during this study were a combination of true and false, multiple choice, and short answer questions in an effort to not rely too heavily on one type of question format and to make the pre and post tests more accurately mirror the format of the students’ traditional assessments. Due to time constraints, these pre and post tests were limited to ten or eleven questions. However, there is an inherent problem of the high risk (50% chance) of unearned correct answers due to guessing with true and false questions, and the subjectivity associated with the awarding of points for short answer questions. Also, the small sample size when using such a small number of assessment questions leads to a much larger chance of error when compiling the students' scores. It is suggested that multiple choice questions, which have a lower incidence of a false positive, and a larger number of questions on the pre and post tests be used in any future studies on the topic.

Group Sizes

The projects used in this study all required students be placed in groups, with each student taking on certain responsibilities. The projects requiring larger group sizes often resulted in social loafing with certain students, and the divvying up of job responsibilities often resulted in specialization, both of which can lead to decreased effectiveness that the projects have on student learning. The occurrence of social loafing and specialization was less apparent as the group sizes were reduced. With smaller group sizes, as with the note card car and mug design projects which required groups of two, the ability of students to specialize and socially loaf were reduced as there were more project responsibilities per person in the group and less opportunity for a group member to "pick up the slack" . The instructor also noted less off task behavior and disruptions with the smaller group sizes. This indicates that when designing future group projects, efforts should be made to minimize the group sizes to the fewest students possible to complete all of the goals of the project.

In conclusion, the use of engineering design projects and PBL strategies in the science classroom can introduce students to different ways of thinking about and applying science content. By providing students with a structured method for solving problems with engineering design principles and placing the student in charge of understanding the relationship between what they have learned in class and how it could be applied to everyday life, they were much more motivated towards and successful in accomplishing their goals and the goals that the instructor had for the students. Further research is suggested on the use of PBL strategies to motivate students in other disciplines.

APPENDICES

Appendix A: Design and Build a Water Filter Project

Prior Knowledge Discussion Questions:

1. Is surface water usually pure or a mixture?
2. If you said a mixture for question 1, is it homogeneous or heterogeneous mixture? Why do you think this?
3. List as many contaminants that are found in surface water as you can. You may list general categories (EX: trace metals) of contaminants or specific examples (EX: Iron) of contaminants.
4. Do you believe you can physically filter out all contaminants listed by yourself and others? Why or why not?
5. What methods do you know that are currently used to clean water of contaminants? List as many as you can, or if you can't think of the process just describe what you know.
6. Some contaminants are dissolved by water to form a solution. This means the water may look clear but actually is still carrying the contaminant. List an example of a place where the water looks clear but there is evidence that it is a solution.
7. How do you think we can remove the contaminants if they have formed a solution?

Four Groups of Contaminants

Microbial Pathogens.

Pathogens in drinking water are serious health risks. Pathogens are disease-producing micro-organisms, which include bacteria (such as giardia lamblia), viruses, and parasites. They get into drinking water when the water source is contaminated by sewage and animal waste, or when wells are improperly sealed and constructed. They can cause gastroenteritis, salmonella infection, dysentery, shigellosis, hepatitis, and giardiasis (a gastrointestinal infection causing diarrhea, abdominal cramps, and gas). The presence of coliform bacteria, which is generally a harmless bacteria, may indicate other contamination to the drinking water system.

Organics.

People worry the most about potentially toxic chemicals and metals in water. Only a few of the toxic organic chemicals that occur drinking water are regulated by drinking water standards.

This group of contaminants includes:

• Trihalomthanes (THMs), which are formed when chlorine in treated drinking water combines with naturally occurring organic matter.
• Pesticides, including herbicides, insecticides, and fungicides.
• Volatile organic chemicals (VOCs), which include solvents, degreasers, adhesives, gasoline additives, and fuels additives. Some of the common VOCs are: benzene, trichloroethylene (TCE), styrene, toluene, and vinyl chloride. Possible chronic health effects include cancer, central nervous system disorders, liver and kidney damage, reproductive disorders, and birth defects.

Inorganics.

These contaminants include toxic metals like arsenic, barium, chromium, lead, mercury, and silver. These metals can get into your drinking water from natural sources, industrial processes, and the materials used in your plumbing system. Toxic metals are regulated in public water supplies because they can cause acute poisoning, cancer, and other health effects.

Nitrate is another inorganic contaminant. The nitrate in mineral deposits, fertilizers, sewage, and animal wastes can contaminate water. Nitrate has been associated with "blue baby syndrome" in infants.

Radioactive Elements.

Radon is a radioactive contaminant that results from the decay of uranium in soils and rocks. It is usually more of a health concern when it enters a home as a soil gas than when it occurs in water supplies. Radon in air is associated with lung cancer.

(EPA, 2011)

<u>Design a Water Purification Procedure Project</u>

<u>Objectives:</u>

- Identify pure substances and mixtures and their differences
- Identify pure substances and solutions and their differences
- Identify substances in a mixture and their properties
- Separate substances based on chemical and physical properties

Water, while incredibly abundant, is not all safe for human consumption. Impurities from salts and metals, to bacteria and viruses are prevalent in much of the water found on Earth, therefore it is important to have effective and cheap processes for "cleaning" or purifying the water of unwanted and potentially harmful contaminants. Environmental engineers are constantly coming up with new and interesting ideas for purifying water for human consumption and agriculture by using knowledge about the chemical, physical, and biological properties of the contaminants.

Your project is to research and develop a device and a procedure for filtering water using cheap and easily available materials.

<u>For Submission:</u>

1. Background Information (Research), ***Individual Grade***
2. Pre/Post Test Observations, ***Group Grade***
3. Step by Step procedure for entire water purification process, ***Group Grade***
4. Post Test Analysis Questions, ***Group Grade***

Group Job Assignment:

Each person in your group will research a process used during water purification. It will be that person's job to design the portion of the purification procedure that corresponds to their research. **It is imperative that each person does their job as the entire group can suffer as a result!** The research areas are as follows:

- Coagulation/Flocculation and Sedimentation
- Disinfection
- Aeration
- Filtering including carbon filtering

In addition to these there will also be a Project Manager that will be leading the incorporation of all of these groups. After your research is completed, you will meet with members of other groups with your same topic and discuss your findings. You will then meet with your group, under the leadership of the Project Manager, to design your purification procedure and construct any devices that you need.

Name: ___________________________________

Coagulation / Flocculation and Sedimentation

Define the following in your own words

Coagulation/Flocculation:

Sedimentation:

How does this process work?

Why is it used in water treatment?

Using the materials on the provided list, design a procedure for the flocculation and sedimentation of the "swamp water". Use the back if needed.

List all sources – if web page list URL and a short description or title. Must have at least 3!

Name: ___________________________________

Disinfection

Define the following in your own words

Disinfection:

How does this process work?

Why is it used in water treatment?

Using the materials on the provided list, design a procedure for the disinfection of the "swamp water". Use the back if needed.

List all sources – if web page list URL and a short description or title. Must have at least 3!

Name: ___________________________________

Aeration

Define the following in your own words

Aeration:

How does this process work?

Why is it used in water treatment?

Using the materials on the provided list, design a procedure for the aeration of the "swamp water". Use the back if needed.

List all sources – if web page list URL and a short description or title. Must have at least 3!

Name: ___________________________________

Filtration and Carbon Filtration

Define the following in your own words

Filtration:

Carbon or Activated CarbonFiltration :

How does this process work?

Why is it used in water treatment?

Using the materials on the provided list, design a procedure for the filtration of the "swamp water". Use the back if needed.

List all sources – if web page list URL and a short description or title. Must have at least 3!

Name: ___________________________________

Project Manager

Create a flow chart of the steps of the water treatment cycle, make sure to include what each stage cleans out of the water.

Other Comments:

List all sources – if web page list URL and a short description or title. Must have at least 3!

<u>**Post Purifying Questions**</u>

1. Prior to any treatment, is your sample a pure substance or a mixture?

2. If it is a mixture, what type of mixture is it: heterogeneous or homogeneous? Provide evidence from your observation table for justification.

3. Do you believe there are also substances dissolved in your swamp water that are not visible to the naked eye? Why do you think this?

4. Are any of the steps in your procedure physically separating out contaminants? If so which ones?

5. Are any of the steps in your procedure chemically separating out contaminants? If so which ones?

6. Based purely on your observations from the table, how would you rate the effectiveness of the purification procedure on a scale of 1 (poor) to 10 (potable or drinking quality)? Why did you rate it the way you did?

Appendix B: Egg Drop Project

Design Process:

Everyday an engineer ponders the questions below. Now it's your turn

- What is the problem ?
- What is the purpose ?
- Who is the user ?
- What are the customer needs ?
- What are some existing products out there already?
- What are the shape/size limitations ?
- What are the material requirements ?
- What are the cost limitations?
- What is the manufacturing time ?
- Product support needs?
- Estimated product life ?

When answering these problems, the engineer works with a team, each assigned a role, and puts their ideas on paper (or computer) so that others may understand them. To do this they use annotated drawings.

Create annotated drawings of all of the major design features of your proposed egg drop device, as well as one overall sketch (two if needed)

Prior Knowledge Questions

1. List as many car safety devices as you can and include a short description of each. This can include devices or features that help you avoid collisions.

2. The main factor in determining how dangerous a crash can be is how much **Force** you have exerted on you. Since **F=ma**, and your **mass** never changes, then the force can be reduced by reducing your rate of **acceleration** (deceleration). Write the equation for acceleration below.

3. When you are in a crash, your **final velocity (Vf)** will always be ____________? INCLUDE UNITS!!!

4. Since Vf is constant, what 2 variables can be changed?________ and ________

5. The period of **time** we are referring to in a crash is when the forces are actually being exerted – in other words, the acceleration (deceleration) occurs only during the fraction of a second time span during the actual collision. Explain why adding even a small amount of padding or shock absorption can have a large effect on lowering the deceleration.

Egg Drop Lab

Objectives:

- Analyze the relationship between acceleration and force applied to an object in collisions
- Apply knowledge of acceleration, velocity, and time of collision to a design project
- Use scientific principles to guide and justify design decisions

You and your teammates have been hired by an egg company to design a container that will keep eggs from breaking in transport. The less materials that are used, the cheaper it will be for your company and the happier your bosses will be (bonus maybe?). You will be judged on your success based on three things:

- If a test egg can successfully survive a fall when dropped from the top of a ladder.
- The amount of materials used
- Primarily: Your design process and justification for design decisions

For Submission:

1. Each member of the design team must include brainstorming ideas on one or multiple pages, clearly labeled and with the name of team member who created it clearly visible.
2. A final design that includes:
    a. Professional sketches of the final design (one of the overall design, and one close up of a specific design feature)
    b. Annotations that describe specific design features including materials used
    c. Filled out design feature recording sheet with at least 5 design features
3. An egg drop container from which the egg can be removed and inserted with minimal effort.

Materials:

- 15 flexible straws
- 10 Large popsicle sticks, or 20 small sticks, or some combination
- .5 meter of duct tape
- 1 sheet of notebook paper
- one egg, medium to large

Hints for Construction

- Remember a large deceleration is what causes the egg to break, just like in a car crash that we described in class. So you need to focus on reducing the deceleration (negative acceleration).
- The equation for acceleration (deceleration) is:

$$\text{Ave. acceleration} = \frac{\Delta \text{velocity}}{\text{time}} = \frac{v_f - v_i}{t}$$

- You will want to focus on:
    - ***Lowering the initial velocity (how fast the container is traveling when it strikes the ground)*** by slowing its fall. Final velocity is always 0 m/s.
    - ***Increasing the amount of time the egg decelerates in (this is the time it takes from when it first strikes the ground to when it comes to a rest)***, even if it is a small amount, by absorbing some of the shock as it strikes the ground
- Every design decision must be justified by relating it to the 2 variables above, so don't do something just because it's "easy" or "looks cool"
- How would you slow its fall using the materials provided? There are many ways to utilize each material.
- Remember you don't have to use all of the materials, in fact the less the better for your company.
- All tools are available to you, including band saws and drill presses.
- Design the device so that it lands on the side you want it to land - don't just expect it to all on its own.
- TEST IT BEFORE THE FINAL TEST!!! It is simple laziness not to.

Name:______________________________

Hour:_______________________________

<u>Egg Drop Lab Questions – complete sentences only</u>

1. What about your design made it successful/unsuccessful? List examples and ***Be Specific and list several things! Drawings are helpful***

2. If given another chance what, specifically, would you change in your design? ***Be Specific and list several things! Drawings are helpful***

Appendix C: Note Card Car Project

Engineering for Efficiency – Minimizing Friction Activity

Objectives:

- Understand the role of forces in determining the motion of an object
- Understand friction and air resistance as forces that oppose motion
- Apply knowledge of what causes friction between two surfaces
- Apply knowledge of law of conservation of energy.

The inventions always start off as a prototype that demonstrates the key concepts but lacks style, comfort, reliability, or efficiency. After proof that the concept works, engineers work to improve upon the design, for example: compare the first Model T Ford to a current automobile, or the first cell phone to new smart phones, etc. These things function just like the original concept but have had great improvements made to them over the years.

Your job is to take a design for a notecard "car" and improve upon its design to minimize frictional and air resistance forces acting on it as it moves. You will be judged based off of how far your "car" goes down the hallway when provided with a fixed amount of energy, as this will indicate how efficient the design is.

For Submission:

1. Brainstorming Sketches, **Individual**
2. Final Design Sketch, **Group**
3. Complete and tested "Car", **Group**
4. Design Feature Sheet, **Group**

Materials and Constraints:

Your design must be able to "catch" a marble that has been released down a ruler ramp that is supported on top of 3 textbooks. Your "car" must be placed within a few inches of the end of the ramp. It must be carried by the marble until it comes to a complete stop. Your design can be of any size or configuration, but must be cut out from a 3x5 notecard. After brainstorming, your group will come together to settle on one final design of which you will create an annotated final sketch and fill out your design feature sheet. This must be completed before testing.

For testing, we will go out into the hallway to have a long stretch of uninterrupted hallway. You can run as many practice runs as time permits, but will only get 3 official trials. The longest of your trial runs will be taken as your grade. Alterations can be made to your design, or you can start from scratch as long as a final design is ready by testing time.

Pre-design Questions

1. What factors can affect how much friction exists between 2 surfaces in contact? (List at least 3)

2. What factors affect how much air resistance a surface has when moving through still air? (list at least 2)

3. Which of the factors from #2 and 3 can you change in your design? Provide ideas for how you could change each in order to improve efficiency.

4. Identify several surfaces that will come into contact to create friction. How could you minimize friction at these points?

Appendix D: Design a Coffee Mug Project

<u>Coffee Mug Design Project</u>

<u>Objectives:</u>

- Apply knowledge of conduction, convection and radiation
- Make material choices based off of physical properties (insulator, conductor)
- Apply scientific principles in a real world engineering design problem to justify decisions

You are a recent hire at the Thermos coffee mug company. The company is attempting to lure in the high end consumer by creating a new travel coffee mug that they can market as "The World's Best Mug!" By this they mean a mug that can keep your coffee hot for a <u>very</u> long time. You have showed some initiative, and so you have been put in charge of designing the new mug. **<u>You need to submit your proposal for the design at the beginning of business tomorrow and it must include the following items:</u>**

1. Each member of the design team must include brainstorming ideas on one or multiple pages, clearly labeled and with the name of team member who created it clearly visible.
2. Group review sheet filled out by another group, with their comments on your design and ideas for improvement.
3. A final design that includes:
    a. Professional sketch of the final design (one or multiple views depending on your needs)
    b. Annotations that describe specific design features including materials used
    c. Filled out design feature recording sheet with heat transfer prevented – need at least 5

<u>Things to consider:</u>

- Your design should focus on preventing the 3 types of energy transfer (conduction, convection, and radiation)
- Remember the states of matter and how it affects heat transfer – foam insulation isn't by nature a good insulator, but the air pockets it holds are!
- Hmmm… what is a better insulator than gases?
- Certain materials are better conductors, some better insulators, plan accordingly
- Heat that transfers by conduction needs direct contact, so surface area in contact with another solid should be minimized
- Radiation is a form of light, how do you prevent light from travelling?

<u>Group Review Sheet</u>

Reviewed by:______________________   ___________________________

____

These are some things that are positives of the design (please bullet point or number comments):

These are some things that you didn't address or that could be improved (please bullet point or number comments):

Additional Comments (optional but helpful!):

Appendix E: Student and Parent Permission Form

PARENTAL CONSENT AND STUDENT ASSENT FORM

Dear Students and Parents/Guardians:

I would like to take this opportunity to welcome you back to school and invite you to participate in a research project, *The Effectiveness of Engineering Design Projects on Enhancing Science Education*, that I will conduct as part of Physical Science this semester. My name is Adam Green. I am your science teacher this upcoming school year (2011-12) and I am also a master's degree student at Michigan State University. Researchers are required to provide a consent form like this to inform you about the study, to convey that participation is voluntary, to explain risks and benefits of participation, and to empower you to make an informed decision. You should feel free to ask the researchers any questions you may have.

What is the purpose of this research? I have been working on effective ways to teach science by incorporating engineering design projects into the curriculum, and I plan to study the results of this teaching approach on student comprehension and retention of the material. The results of this research will contribute to teachers' understandings about the best way to teach about science topics. Completion of this research project will also help me to design and write my thesis and to earn my master's degree in Michigan State University's Division of Math and Science Education (DSME).

What will students do? You/your student will participate in instructional units about introductory physical science concepts being applied to complete engineering design projects. You/your student will complete the usual assignments, laboratory experiments and activities, computer simulations, class demonstrations, and pretests/posttests just as you do for any other unit of instruction. There are no unique research activities – **participation in this study will not increase or decrease the amount of work that students do**. I will simply make copies of students' work for my research purposes. This project will take place throughout the year (depending upon the trimesters that I have you in class). I am asking for permission from both students and parents/guardians (one parent/guardian is sufficient) to use copies of student work for my research purposes. This project will continue till the end of the school year/2nd trimester of class.

What are the potential benefits? My reason for doing this research is to learn more about improving the quality of science instruction. I won't know about the effectiveness of my teaching methods until I analyze my research results. If the results are positive, I can apply the same teaching methods to other science topics taught in this course, and you will benefit by better learning and remembering of course content. I will report the results in my master's thesis so that other teachers and their students can benefit from my research.

What are the potential risks? There are no foreseeable risks associated with completing course assignments, laboratory experiments and activities, computer simulations, class demonstrations, and pretests/posttests. In fact, completing course work should be very beneficial to students. Consent forms (where you say “yes” or “no”) will be stored in a sealed envelope, in a locked file cabinet that will not be opened until after I have assigned the grades for the entire school year. That way I will not know who agrees to participate in the research until after grades are issued in order to prevent bias. In the meantime, I will save all of your written work. Later I will analyze the written work only for students who have agreed to participate in the study and whose parents/guardians have consented.

How will privacy and confidentiality be protected? Information about you will be protected to the maximum extent allowable by law. Students' names will not be reported in my master's thesis or in any other dissemination of the results of this research. Instead, the data will consist of class averages and samples of student work that do not include names. After I analyze the data to determine class averages and choose samples of student work for presentation in the thesis, I will destroy the copies of student's original assignments, tests, etc. The only people who will have access to the data are me, my thesis committee at MSU, and the Institutional Review Board at MSU. The data will be stored on password-protected computers (during the study) and in a locked file cabinet in Dr. Heidemann's (my thesis coordinator) locked office at MSU (after the study) for at least three years after the completion of the study.

What are your rights to participate, say no, or withdraw? Participation in this research is completely voluntary. You have the right to say “no”. You may change your mind at any time and withdraw. If either the student or parent/guardian requests to withdraw, the student's information will not be used in this study. There are no penalties for saying “no” or choosing to withdraw.

Who can you contact with questions and concerns? If you have concerns or questions about this study, such as scientific issues, how to do any part of it, or to report an injury, please contact the researcher Adam Green: 10000 Moscow Rd. Rm 107, Horton, MI, 49246; adamgreen@hanoverhorton.org; 517-563-0101 ext 420 and /or Dr. Merle Heidemann: 118 North Kedzie Lab , Michigan State University, East Lansing, MI 48824; heidema2@msu.edu; 517-432-2152 x 107].

If you have questions or concerns about your role and rights as a research participant, would like to obtain information or offer input, or would like to register a complaint about this study, you may contact, anonymously if you wish, the Michigan State University's Human Research Protection Program at 517-355-2180, Fax 517-432-4503, or e-mail irb@msu.edu or regular mail at 207 Olds Hall, MSU, East Lansing, MI 48824.

How should I submit this consent form? If you agree to participate in this study, please complete the attached form. Both the student and parent/guardian must sign the form. Return the form to the designated teacher (to be named later) by two weeks from the beginning of the first trimester in which you/your student are enrolled in Physical Science .

Name of science course: Physical Science
Teacher: Adam Green
School: Hanover Horton High School

Parents/guardians should complete this following consent information:

I voluntarily agree to have ____ participate in this study. (print student name)

Please check all that apply:

Data:

___________ I give Adam Green permission to use data generated from my child's work in this class for her thesis project. All data from my child shall remain confidential.

___________ I do not wish to have my child's work used in this thesis project. I acknowledge that my child's work will be graded in the same manner regardless of their participation in this research.

Photography, audiotaping, or videotaping:

___________ I give Adam Green permission to use photos, audiotapes, or videotapes of my child in the class room doing work related to this thesis project. I understand that my child will not be identified.

___________ I do not wish to have my child's images used at any time during this thesis project.

Signatures:

____ __________________________
(Parent/Guardian Signature) (Date)

I voluntarily agree to participate in this thesis project.

____ ___________________________
(Student Signature) (Date)

*****Important*****

Return this form to the teacher designated by Mr. Green – Not to Mr. Green himself!

Appendix F: Design and Build a Water Filter Project Pre/Post Test

Name:____Date:___________Hour:______

Water Purification Pre/Post Test

Directions:

Answer the following T/F questions by writing a T or F on the space provided and include a short but thorough description as to why you answered the way you did.

1. _____ A Pure Substance can contain multiple types of particles if they are small enough to be invisible to the naked eye.

2. _____ Pure substances can contain multiple types of individual, non bonded atoms, but not multiple types of individual molecules.

3. _____ Salt water is an example of a homogenous mixture, not a heterogeneous mixture.

4. _____ The process of dissolving a substance in a liquid is a physical change.

5. _____ Substances that are dissolved in a solution can be removed by pouring the solution through a filter.

Answer the following multiple choice questions by circling the letter of the correct answer.

6. In regards to its classification as a pure substance or a mixture - which of the following substances does not belong with the others?
   a. Orange juice
   b. Blood
   c. Toilet bowl cleaner
   d. Mercury

7. If you add oil to water and shake the liquid, you will form a
   a. Pure substance
   b. Heterogeneous mixture
   c. Solution
   d. Miscible liquid

8. Bubbles are released from cola and when alka seltzer is placed in water. Identify the correct statement.
   a. Cola releasing bubbles is a physical change, and alka seltzer releasing bubbles is a physical change
   b. Cola releasing bubbles is a physical change, and alka seltzer releasing bubbles is a chemical change
   c. Cola releasing bubbles is a chemical change, and alka seltzer releasing bubbles is a physical change
   d. Cola releasing bubbles is a chemical change, and alka seltzer releasing bubbles is a chemical change

9. A heterogeneous mixture is one in which
   a. All the different substances chemically combine so that they are indistinguishable from one another
   b. All the different substances stay separate but are too small to be seen with the naked eye
   c. All the substances are separate to form layers based on density
   d. All of the substances stay separate and are large enough to be seen with the naked eye

10. Which most accurately describes carbon dioxide
    a. Element
    b. Compound
    c. Mixture
    d. Solution

Answer the following essay question completely and thoroughly.

11. Describe how you can tell that a sugar dissolves in water to form a mixture (solution) and does not undergo a chemical reaction to form a new substance.

Water Purification Pre/Post Test Rubric

/11

Directions:

Answer the following T/F questions by writing a T or F on the space provided and include a short but thorough description as to why you answered the way you did.

1. __F___ A Pure Substance can contain multiple types of particles if they are small enough to be invisible to the naked eye. (+1)

   Pure substances contain only one type of particle

2. __F___ Pure substances can contain multiple types of individual, non bonded atoms, but not multiple types of individual molecules. (+1)

   Pure substances can contain only one type of atom or molecule

3. __T___ Salt water is an example of a homogenous mixture, not a heterogeneous mixture. (+1)

   Any solution is homogeneous

4. __T___ The process of dissolving a substance in a liquid is a physical change. (+1)

   No new substances are formed

5. ___F__ Substances that are dissolved in a solution can be removed by pouring the solution through a filter. (+1)

   Filters to remove dissolved particles require pressure

Answer the following multiple choice questions by circling the letter of the correct answer.

6. In regards to its classification as a pure substance or a mixture – which of the following substances does not belong with the others? (+1)
   a. Orange juice
   b. Blood
   c. Toilet bowl cleaner
   d. <u>Mercury</u>

7. If you add oil to water and shake the liquid, you will form a(+1)
   a. Pure substance
   b. <u>Heterogeneous mixture</u>
   c. Solution
   d. Miscible liquid

8. Bubbles are released from cola and when alka seltzer is placed in water. Identify the correct statement. (+1)
   a. Cola releasing bubbles is a physical change, and alka seltzer releasing bubbles is a physical change
   b. <u>Cola releasing bubbles is a physical change, and alka seltzer releasing bubbles is a chemical change</u>
   c. Cola releasing bubbles is a chemical change, and alka seltzer releasing bubbles is a physical change
   d. Cola releasing bubbles is a chemical change, and alka seltzer releasing bubbles is a chemical change

9. A heterogeneous mixture is one in which(+1)
   a. All the different substances chemically combine so that they are indistinguishable from one another
   b. All the different substances stay separate but are too small to be seen with the naked eye
   c. All the substances are separate to form layers based on density
   d. <u>All of the substances stay separate and are large enough to be seen with the naked eye</u>

10. Which most accurately describes carbon dioxide(+1)
    a. Element
    b. <u>Compound</u>
    c. Mixture
    d. Solution

Answer the following essay question completely and thoroughly.

11. Describe how you can tell that a sugar dissolves in water to form a mixture (solution) and does not undergo a chemical reaction to form a new substance. (+1)

No signs of a chemical change (bubbling, color change, temp change, etc) substances maintain their physical properties

Appendix G: Egg Drop Project Pre/Post Test

Name:____Date:___________Hour:______

Egg Drop Pre/Post Test

Directions:

Answer the following T/F questions by writing a T or F on the space provided and include a short but thorough description as to why you answered the way you did.

1. _____ 30 m/s represents a velocity

2. _____ As the time required for a car to come to a stop increases, the acceleration (deceleration) decreases

3. _____ The larger the acceleration of an object, the larger the force acting on the object.

4. _____ When the final velocity of an object is less than the initial velocity of the object, there is a negative acceleration.

5. _____ It is possible to have a negative acceleration and be speeding up.

Answer the following multiple choice questions by circling the letter of the correct answer.

6. Doing which of the following would reduce the magnitude of acceleration in all cases?
   a. Decrease time that an object accelerates
   b. Increasing the magnitude velocity final of the object
   c. Increasing the magnitude on the velocity initial
   d. Increase the time that an object accelerates

7. A force is continuously applied to a grocery cart causing it to accelerate. After a while, the cart stops accelerating even though the force is still being applied. What conclusion can be drawn.
   a. The mass of the cart has increased
   b. The gravity acting on the cart has increased
   c. The cart is experiencing some kind of friction
   d. The momentum of the cart has reached its maximum

8. A seatbelt helps a driver during a car crash by
   a. Decreasing the acceleration on the driver during the collision
   b. Increasing the acceleration on the driver during the collision
   c. Increasing the velocity initial of the driver during the collision
   d. Decreasing the velocity initial of the driver during the collision

9. Which statement about acceleration is true
   a. Acceleration always occurs in the same direction as motion of the object
   b. When the same force is applied to two objects of different masses, they both accelerate at the same rate
   c. Acceleration can occur only when an object changes its speed
   d. Acceleration is the rate at which velocity changes

Answer the following essay question completely and thoroughly.

10. Describe how an airbag can protect the occupants of a car from injuries in a collision more than a collision without one. Use terms such as: velocity final, velocity initial, time, acceleration, and force.

Egg Drop Pre/Post Test Rubric

/10

Directions:

Answer the following T/F questions by writing a T or F on the space provided and include a short but thorough description as to why you answered the way you did.

1. __F___ 30 m/s represents a velocity(+1)

   Needs a speed and a direction

2. __T___ As the time required for a car to come to a stop increases, the acceleration (deceleration) decreases(+1)

   Time and acceleration are inversely proportional

3. ___T__ The larger the acceleration of an object, the larger the force acting on the object. (+1)

   F=ma

4. __T___ When the final velocity of an object is less than the initial velocity of the object, there is a negative acceleration. (+1)

   Change in velocity is negative when Vf < Vi

5. ___T__ It is possible to have a negative acceleration and be speeding up. (+1)

   If you are moving in the negative direction

Answer the following multiple choice questions by circling the letter of the correct answer.

6. Doing which of the following would reduce the magnitude of acceleration in all cases? (+1)
   a. Decrease time that an object accelerates
   b. Increasing the magnitude velocity final of the object
   c. Increasing the magnitude on the velocity initial
   d. <u>Increase the time that an object accelerates</u>

7. A force is continuously applied to a grocery cart causing it to accelerate. After a while, the cart stops accelerating even though the force is still being applied. What conclusion can be drawn. (+1)
   a. The mass of the cart has increased
   b. The gravity acting on the cart has increased
   c. <u>The cart is experiencing some kind of friction</u>
   d. The momentum of the cart has reached its maximum

8. A seatbelt helps a driver during a car crash by(+1)
   a. <u>Decreasing the acceleration on the driver during the collision</u>
   b. Increasing the acceleration on the driver during the collision
   c. Increasing the velocity initial of the driver during the collision
   d. Decreasing the velocity initial of the driver during the collision

9. Which statement about acceleration is true(+1)
   a. Acceleration always occurs in the same direction as motion of the object
   b. When the same force is applied to two objects of different masses, they both accelerate at the same rate
   c. Acceleration can occur only when an object changes its speed
   d. <u>Acceleration is the rate at which velocity changes</u>

Answer the following essay question completely and thoroughly.

10. Describe how an airbag can protect the occupants of a car from injuries in a collision more than a collision without one. Use terms such as: velocity final, velocity initial, time, acceleration, and force. (+1)

The air bag increases the time over which the collision takes place by beginning the collision sooner when it is activated. This decreases the deceleration of the occupant thereby decreasing the force acting on them.

Appendix H: Note Card Car Project Pre/Post Test

Name:____Date:___________Hour:______

Notecard Car Pre/Post Test

Directions:

Answer the following T/F questions by writing a T or F on the space provided and include a short but thorough description as to why you answered the way you did.

1. _____ If an object is stationary, then it has no forces acting on it.

2. _____ An object's acceleration is always in the direction of the net force.

3. _____ If a bowling ball strikes a kickball, the force that the bowling ball exerts on the kickball is the same as the force that the kickball exerts on the bowling ball.

4. _____Suppose you are pushing a car with a certain net force. If you push the car with twice that net force the acceleration of the car will double.

5. _____ Friction is decreased between two objects by increasing the surface area in contact between the two objects thus spreading out the force over more area .

Answer the following multiple choice questions by circling the letter of the correct answer.

6. Using the provided force diagram identify the direction of motion of the following object.

    a. To the right
    b. To the left
    c. There is no motion
    d. This question cannot be answered with the given information

7. If a baseball is thrown at a high speed at a stationary bowling ball suspended by a cable from the ceiling, upon collision the bowling ball will
    a. Accelerate away from the baseball, but at a lower speed than the baseball was thrown
    b. Accelerate away from the baseball, at the same speed as the baseball was thrown
    c. The baseball will not make the bowling ball move as the force that it applies will be much smaller than the force that the bowling ball applies to the baseball

8. If you are standing on a skateboard and jump forward the skateboard will accelerate backward much faster than you will accelerate forward. This is caused by
    a. A much larger force being applied to the skateboard than to you
    b. The low friction that the skateboard has with the ground
    c. The skateboard does not have a force acting in the opposite direction of your push
    d. The mass of the skateboard is much less than your mass

9. A marble and a bowling ball are dropped from the same height. The force of gravity acting on the bowling ball is much larger than the force of gravity acting on the marble yet both fall at the same rate. Why?
    a. Air resistance is much greater on the bowling ball than it is on the marble, accounting for the same acceleration
    b. The mass of the bowling ball is much bigger, so it requires a larger force to accelerate it at the same rate as the marble
    c. The marble is smaller and has less air resistance so it can fall as fast as the bowling ball

Answer the following essay question completely and thoroughly.

10. Use the law of conservation of momentum to explain the phenomenon of a golf club striking a golf ball, and the golf ball travelling faster than the golf club was when the collision took place.

Notecard Car Pre/Post Test Rubric

/10

Directions:

Answer the following T/F questions by writing a T or F on the space provided and include a short but thorough description as to why you answered the way you did.

1. __F___ If an object is stationary, then it has no forces acting on it.(+1)

   No Net Force

2. __T___ An object's acceleration is always in the direction of the net force. (+1)

   Net Force accelerates the direction of the net force

3. ___T___ If a bowling ball strikes a kickball, the force that the bowling ball exerts on the kickball is the same as the force that the kickball exerts on the bowling ball. (+1)

   Newton's third law

4. ___T___Suppose you are pushing a car with a certain net force. If you push the car with twice that net force the acceleration of the car will double. (+1)

   Net force and acceleration are directly proportional

5. __F___ Friction is decreased between two objects by increasing the surface area in contact between the two objects thus spreading out the force over more area . (+1)

   Friction is dependent on surface area in contact

Answer the following multiple choice questions by circling the letter of the correct answer.

6. Using the provided force diagram identify the direction of motion of the following object. (+1)
   - **a. To the right**
   - b. To the left
   - c. There is no motion
   - d. This question cannot be answered with the given information

7. If a baseball is thrown at a high speed at a stationary bowling ball suspended by a cable from the ceiling, upon collision the bowling ball will(+1)
   - **a. Accelerate away from the baseball, but at a lower speed than the baseball was thrown**
   - b. Accelerate away from the baseball, at the same speed as the baseball was thrown
   - c. The baseball will not make the bowling ball move as the force that it applies will be much smaller than the force that the bowling ball applies to the baseball

8. If you are standing on a skateboard and jump forward the skateboard will accelerate backward much faster than you will accelerate forward. This is caused by(+1)
   - a. A much larger force being applied to the skateboard than to you
   - b. The low friction that the skateboard has with the ground
   - c. The skateboard does not have a force acting in the opposite direction of your push
   - **d. The mass of the skateboard is much less than your mass**

9. A marble and a bowling ball are dropped from the same height. The force of gravity acting on the bowling ball is much larger than the force of gravity acting on the marble yet both fall at the same rate. Why? (+1)
   - a. Air resistance is much greater on the bowling ball than it is on the marble, accounting for the same acceleration
   - **b. The mass of the bowling ball is much bigger, so it requires a larger force to accelerate it at the same rate as the marble**
   - c. The marble is smaller and has less air resistance so it can fall as fast as the bowling ball

Answer the following essay question completely and thoroughly.

10. Use the law of conservation of momentum to explain the phenomenon of a golf club striking a golf ball, and the golf ball travelling faster than the golf club was when the collision took place. (+1)

The momentum of the golf club is transferred to the golf ball but because of the golf balls lower mass it will have a larger velocity due to the law of conservation of momentum.

Appendix I: Coffee Mug Design Project Pre/Post Test

Name:____Date:___________Hour:______

Mug Design Pre/Post Test

Directions:

Answer the following T/F questions by writing a T or F on the space provided and include a short but thorough description as to why you answered the way you did.

1. _____ The state of matter that allows convection to occur the most efficiently is solid.

2. _____ Radiation is the only energy transfer that can occur in a vacuum like space

3. _____ A very dense solid metal would make an efficient insulator.

4. _____ Putting an ice cube into a glass of water lowers the total amount of energy in the glass.

5. _____ The highest temperature in a home is near the ceiling of the top floor. This is due to convection.

Answer the following multiple choice questions by circling the letter of the correct answer.

6. The energy transfer that relies on the direct contact of particles is
   a. convection
   b. conduction
   c. radiation
   d. a and b
   e. b and c
   f. a and c

7. Which of the following materials is the poorest conductor of energy as heat.
   a. plastic
   b. helium gas
   c. cotton
   d. aluminum

8. When you place your hand on a metal surface that is at room temperature it feels cold, but when you put your hand on a plastic object at the same temperature it doesn't feel cold. Why?
   a. The plastic is a better conductor so heat is transferred from the surroundings to your hand more easily
   b. The metal is a better insulator so cold is more quickly transferred into your hand
   c. The plastic is a better insulator so cold cannot transfer quickly into your hand
   d. The metal is a better conductor so heat can transfer quickly from your hand

9. When a hot block of iron is placed in a container of water
   a. Kinetic Energy of the particles is transferred from the metal into the water by conduction
   b. Kinetic Energy of the particles is transferred from the water into the metal by conduction
   c. Kinetic Energy of the particles is transferred from the metal into the water by convection
   d. Kinetic Energy of the particles is transferred from the metal into the water by radiation

Answer the following essay question completely and thoroughly.

10. Using the law of conservation of energy and the types of energy transfers, describe movement of heat of a cup of hot tea left on the table for a few hours.

Mug Design Pre/Post Test Rubric

/10

Directions:

Answer the following T/F questions by writing a T or F on the space provided and include a short but thorough description as to why you answered the way you did.

1. __F___ The state of matter that allows convection to occur the most efficiently is solid.(+1)

   Solids do not allow the migration of particles necessary for convection

2. ___T__ Radiation is the only energy transfer that can occur in a vacuum like space(+1)

   Radiation does not require particles

3. __F___ A very dense solid metal would make an efficient insulator. (+1)

   The closer the particles the more efficient energy can conduct through them

4. ___F__ Putting an ice cube into a glass of water lowers the total amount of energy in the glass. (+1)

   Average KE (temperature) is lowered but ice cubes still have energy so total KE is increased

5. ___T__ The highest temperature in a home is near the ceiling of the top floor. This is due to convection. (+1)

   Warm, less dense air rises due to convection currents

Answer the following multiple choice questions by circling the letter of the correct answer.

6. The energy transfer that relies on the direct contact of particles is(+1)
   a. convection
   b. <u>conduction</u>
   c. radiation
   d. a and b
   e. b and c
   f. a and c

7. Which of the following materials is the poorest conductor of energy as heat. (+1)
   a. plastic
   b. <u>helium gas</u>
   c. cotton
   d. aluminum

8. When you place your hand on a metal surface that is at room temperature it feels cold, but when you put your hand on a plastic object at the same temperature it doesn't feel cold. Why? (+1)
   a. The plastic is a better conductor so heat is transferred from the surroundings to your hand more easily
   b. The metal is a better insulator so cold is more quickly transferred into your hand
   c. The plastic is a better insulator so cold cannot transfer quickly into your hand
   d. <u>The metal is a better conductor so heat can transfer quickly from your hand</u>

9. When a hot block of iron is placed in a container of water(+1)
   a. <u>Kinetic Energy of the particles is transferred from the metal into the water by conduction</u>
   b. Kinetic Energy of the particles is transferred from the water into the metal by conduction
   c. Kinetic Energy of the particles is transferred from the metal into the water by convection
   d. Kinetic Energy of the particles is transferred from the metal into the water by radiation

Answer the following essay question completely and thoroughly.

10. Using the law of conservation of energy and the types of energy transfers, describe movement of heat of a cup of hot tea left on the table for a few hours. (+1)

KE will convect away through the surface of the tea, conduct through the cup into the air and to the table, and radiate out through the cup and into the air.

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