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Reverse Engineering For Freshman through Senior

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Reverse Engineering For Freshman through Senior

By

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Report
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Dedication

This work is dedicated to my engineering students at Victoria West High school. They have unknowingly been my teacher and I have been their grateful student.

Acknowledgements

I would like to thank the Masters of Engineering Education (MASEE) program at the University of Texas for allowing me to discover the benefits that high school engineering offers to its students, and the culmination of that knowledge in this report.

I would also like to thank Dr. Richard Crawford for his inspiring MASEE graduate courses in Engineering, which included reverse engineering. Without those courses this report would not be possible.

Abstract

Reverse Engineering for Freshman to Seniors

by

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The University of Texas at Austin, 2015

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Reverse Engineering is the process of discovering the workings of a device or system through analysis. It is a high interest activity for high school engineering classes. In general, high school students have not had much experience taking devices apart and determining how they work, but they are often very interested when given the opportunity. Also, the device chosen can be a culminating activity from which to teach physics and engineering principles such as electricity, motors, gears, cams, etc. In addition, Reverse Engineering activities can incorporate elements of engineering design such as Black Box Modeling, Affinity Analysis, and many more.

This report looks at the progression of high school Reverse Engineering activities from freshman to senior courses, including device choice, pre-teaching, documentation, and associated design activities. The goal is to start at the freshman level and gradually build the skills needed to complete the Generator Flashlight Reverse Engineering Project in the *Engineer Your World* curriculum.

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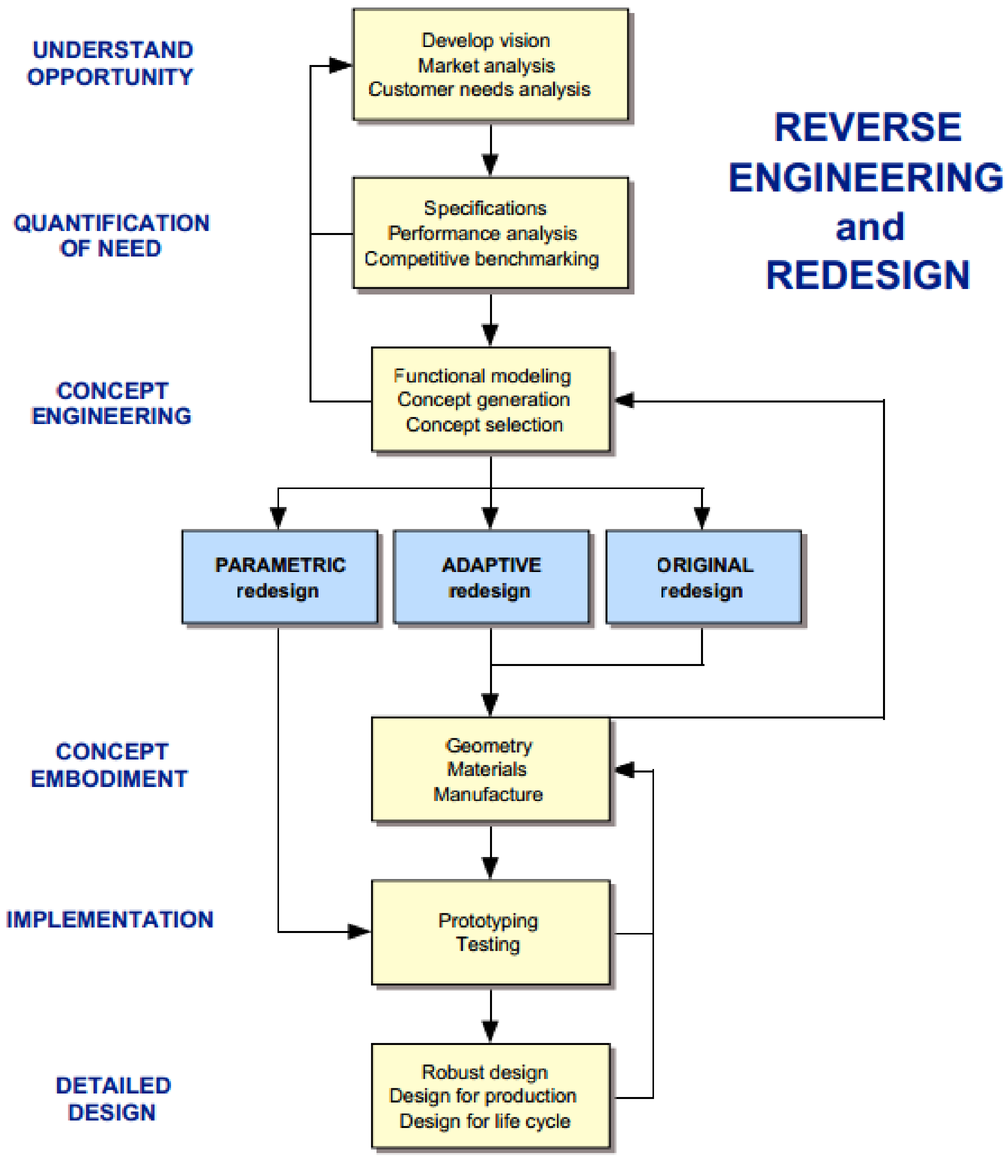
Chapter 1: Introduction

1.1 What is Reverse Engineering

Reverse Engineering is the process of discovering the workings of a device or system through analysis. In this case, it involves disassembling the device and analyzing its components in detail. It is often used in industry for maintenance, to duplicate a device, or to improve upon a device. Of course there are potential ethics issues for copyrights and patents that must be considered. These issues are not addressed in this study.

1.2 Reverse Engineering Design Process

Figure 1: Reverse Engineering and Redesign Process (UTeachEngineering Curriculum)



1.3 Current High School Curriculum

Reverse Engineering is one unit in the University of Texas *Engineer Your World* (EYW) curriculum for seniors. The course can be offered as a fourth year science credit toward high school graduation. Texas also has high school engineering courses for freshman and sophomores, but there is no known reverse engineering curriculum for the lower level courses, aside from occasional lesson plans on the internet. Well known high school engineering curriculum includes *Engineer Our World*, *Engineer the Future*, *Engineer Your World, Infinity, Project Lead the Way, Ford PAS, ITEEA,* companies such as Pitsco that sell project kits, and lesson plans on the internet. Engineer Your World is has far and above a more comprehensive reverse engineering unit for high school seniors than the other curriculums listed.

1.4 Curriculum Goals

Curriculum goals for a progression of reverse engineering lessons are 1) to progess high school underclassmen skills for the Engineer Your World course, and 2) to ready all our students for freshman engineering at a university, commonly Texas A&M and University of Texas (UT).

The goal for this report is to discuss curriculum components for reverse engineering for 9-11th grade courses, that will lead up to and prepare students for the Generator Flashlight Reverse Engineering Project in the *Engineer Your World* curriculum, as well as help prepare the students for freshman engineering at a university. Of particular interest is the choice of device that should be used at each grade level, commensurate with the background of the students. The assignments, worksheets, drawings included in the lessons should support the next grade level and allow for a progression of knowledge of the process of reverse engineering. Last but not least, the lesson, including the device, should be easy to implement in the classroom, and maintain a high level of interest to the students, especially the non-typical engineering students.

Chapter 2: Review

2.1 Industry and College Benefits

Reverse Engineering is the scientific method of taking something apart in order to figure out how it works. It has been used by innovators to determine a product's structure in order to develop competing or interoperable products. Reverse Engineering is an invaluable teaching tool used by researchers, academics and students in engineering (Mani).

Industry also benefits from reverse engineering. It is used by competitors to disassemble and discover the trade secrets within. They use such information to innovate their own products (Mani). The vendor Q PLUS Labs in Irvine, CA specializes in assisting its customers with reverse engineering, either competitors' products or their own products or parts. They offer the equipment needed to measure the device and then produce 3-D drawings of it. Their website lists the following applications for reverse engineering: replicating objects, product development, assessing objects, product definition, and object interfacing (Q Plus). Their customers might include business owners, governments, and other organizations. They suggest there are two avenues to pursue when reverse engineering is needed: outsourcing or purchasing equipment to perform the reverse engineering in-house (Q Plus).

Steven Shooter from Bucknell University discusses the real life case study of the "Stapler Wars" which occurred in 2006. The subject is the innovative line of staplers developed and sold by Accentra. Accentra has seen remarkable success selling a new line of staplers with a mechanical advantage and spring loaded stapler, and they attribute their new design in part to reverse engineering (Bucknell, 2008).

At the college level, dissection (or reverse engineering) has many academic benefits that are both direct and indirect on the formation of a design-oriented engineering student. Dr. Sheri D. Sheppard, at Stanford University, has run a very successful mechanical dissection laboratory and gives many examples of student impact (Hubbard, et.al. 2011). Foremost is an awareness of the design process; students realize that products do not just appear and that design involves many tradeoffs amongst the possible solutions. The practical benefits are numerous as well, where students gain valuable "hands-on" experience as many engineering students have little experience in the area (Hubbard, et.al. 2011). As a side note, in 2013 the author conducted research at Stanford by asking freshman students at a Stanford Engineering Fair what they wished their high school had offered them to prepare them for engineering at Stanford. Five out of five freshman engineering students said "hands-on projects."

Dissection also provides students with an opportunity to examine other people's solution to a problem. According to Sheppard, it is during this examination that the instructor can prompt the students to reason out why the design's form and functions are the way they are (Hubbard, et.al. 2011).

Since one of the goals of the author's high school curriculum is to ready engineering students for university freshman engineering, feedback from universities such as Stanford are valuable to this research. The Stanford students in the article are using a Kitchen Aid Stand Alone mixer – a very complex device with complex gears, electrical, and mechanical systems. Since many devices used for reverse engineering are mechanical and electrical in nature, it follows that a high school curriculum for reverse engineering might include devices with these characteristics.

The New Jersey Institute of Technology at Newark, NJ allows their freshman engineering student team to choose their own device to reverse engineer. Past devices include bicycle chain, drum base pedal, paper trimmer, single cylinder engine, dial padlock, skate board, etc. This project is characterized by extensive journaling of the parts, their function, a 3D model, and reassembly. At the culmination they have a Reverse Engineering Showcase much like a science fair, and each team presents a poster and technical report. The positive impact that spawned from the students' immersion in Reverse Engineering does not stop at the end of the fourteen week semester. Apart from inspiring freshman, Reverse Engineering also provides a practical means to foster innovation. Students who showed a flair for innovation during the project phase are invited to participate in a newly begun extracurricular activity, named the Innovative Design and Engineering Activity Idea. (Mani)

Arizona State University also does reverse engineering activities. One such student report reverse engineered a milkshake maker. The report was highly technical in nature, with 3-D drawings and mathematical analysis of the individual parts (Swanson, 2003). While this is too rigorous for a high school curriculum, it does show us what might be in the high school engineering student's future. Precursors to this type of activity should be considered for a high school curriculum. Examples of why a device might be too rigorous for high school might include too many parts, the level of sophistication of the interior workings, and the amount of background knowledge required to understand how the product works, to name a few.

The MASEE program at the University of Texas uses a hair dryer for their reverse engineering project. It is used in a course taken by future or current high school engineering teachers. It is presented more from the angle of what and how to teach reverse engineering to high school students, so it might be less rigorous than reverse engineering projects of college engineering students, but more enlightening about the valuable techniques used in reverse engineering.

2.2 Previous University of Texas Masters Theses/Reports

There are four previous UT Master's theses/reports related to Reverse Engineering. In Todd Connell Head's report "Reverse Engineering Toolbox," his research recommends tools that a teacher should maintain for reverse engineering activities, including those that are useful for a wide variety of products and those that are more specialized (Connell, 2011). In Jeremy Guillory report "Foundations of a Reverse Engineering Methodology," he explains methodologies for extracting technical data from electro-mechanical products for the purpose of recreating them functionally and dimensionally (Guillory, 2011). Roy George Eid's report "Reverse Engineering Toolbox for Pedagogical Applications," sounds a lot like Todd Connell's report, but it deals with more complex issues at a more rigorous level (Eid, 2012). Connell's report is more geared toward practical application for a high school teacher. The last Master's report is by Nicole Lane Howard and is titled "Redesigning Reverse Engineering Curriculum," It focused on adding various writing and reflection exercises, and specification sheets and rubrics to the *Engineer Your World* reverse engineering curriculum (Howard, 2011). Connell's and Eid's reports can be used when specifying the tools needed for the reverse engineering lesson. Guillory can be used for the methodologies, and Howard can be used for worksheets and assignments. All of them will be used in concert to help determine which devices should be used in the experimental procedure, which is discussed in the following paragraphs.

2.3 Reverse Engineering Software

Another facet of reverse engineering is its use with software. There are no known examples of reverse engineering lesson plans for software for high school curriculum, however an exhaustive list of “devices” to use for reverse engineering must include software. A Google search for “reverse engineering” yields a plethora of hits on software reverse engineering. This type of reverse engineering might prove difficult to implement at the high school level since many high schools barely teach programming at all, and reverse engineering software is an advanced topic for computer science classes. This is the opposite for a simple device such as a can opener, which can be an introductory unit or an advanced unit in an engineering course, depending on the goals of the lesson. An engineering class might contain some students with programming experience but not likely all. For these reasons, this research will not be considering reverse engineering of software in this paper.

Chapter 3: Elements of Reverse Engineering

3.1 Choosing a Device

One of the first decision's that must be made for a reverse engineering lesson is to decide which device to use. Research on the internet and other curriculums yields a variety of devices, including *Engineer Your World*'s generator pig flashlight for senior level. Texas Education Agency's University of North Texas High School engineering curriculum uses a hand held can opener for a freshman class. Project Lead the Way allows the high school student to select a machine with a minimum of eight parts, such as a dial indicator, automobile alternator, sprinkler head, saber saw, computer hard drive, mixer motor, or pneumatic pressure regulator. Georgia Career and Technical Resource Network reverse engineering lesson uses an ink pen for grades 9-12. Science Olympiad Fringe lesson plan uses a disposable camera for 9-12 grades. University of Texas at Austin allows the student team to pick the device with guidance from the instructor. Past devices have included a baby toy, bathroom scale, beer faucet, bicycle pump, bolt cutter, can opener, corkscrew, deadbolt lock, and desktop clamp (Barr, et.al. 2009). Khan Academy shows videos on reverse engineering of a radio, coffee maker, tap light, hair dryer, DVD player, universal remote, and digital camera. Various other lesson plans on the internet use an electric drill, blender, electric mixer or knife, flashlight, pinwheel on a pencil to lift a cup, hair dryer, a machine with 12-24 parts, cubelets, wind up toys, unique dollar store products, portable tools, an entire device or only a part of a device. While there exists a multitude of research touting the benefits of reverse engineering, there is no known research on what kind of devices are best for certain student populations. This is because, to some, the process is more important than the device. However, the selection of a device can be critical to the success of the lesson, depending on the goal of the lesson. Goals may include teaching mechanical or electrical concepts, the Engineering Design Process through concepts like black box modelling or activity diagrams. Student engagement, interest level of non-traditional engineering students, ease of availability and cost for the teacher, and frustration level of students due to a device that is too simple or too complex based on prior knowledge of that grade level could be issues.

3.2 Inclusion of Drawings and Written Assignments

The inclusion of drawings in a reverse engineering lesson is almost universal. A review of lessons on the internet shows that most lessons use hand sketches, especially for younger students. Some lessons don't specify hand drawn or CAD but do specify the level of detail. The issue of whether to require CAD and/or 3D drawings or hand sketches is much like the software dilemma above, in that any given high school class can have students with CAD experience or not. Unless the course taught a unit of CAD before the reverse engineering unit, they cannot require CAD drawings. On the other hand, Barr describes a reverse engineering project for an Engineering Graphics (Autocad) course at the University of Texas at Austin. The list of documents to turn in for the project include three different graphic organizers and seven different drawings, all done in Autocad or 3D software (Barr, et.al. 2009) Reverse engineering can involve several drawings, and the teacher must carefully decide how to include those drawings. Barr states that the project not only exercises the graphics and modeling fundamentals but also extends the student activities to analysis and prototyping (Barr, et.al. 2009)

Written assignments such as descriptions, parts lists, mass properties report, materials and manufacturing analysis, discussion of ethical issues, and assembled final report are usually included in reverse engineering lessons (Barr, et.al. 2009). Graphic organizers/models such as fishbone diagrams, black box modelling, activity diagrams, and Gantt charts (Balraj, 2013) can also be included. Nicole Lane Howard's Master's Report examines the writing acitivities in a reverse engineering lesson and presents rubrics for grading (Howard, 2011). Some of these activities are more involved or rigorous than others, and curriculum that is a progression for 9-11th graders would need to consider which of these is appropriate for what grade level. For example, 9th graders may become confused if too many activities and graphic organizers are presented too quickly, but they can certainly take apart a can opener and determine how it works. Juniors, on the other hand, after already having experiences in reverse engineering as freshman and sophomores, might be able to wisely choose their own device, and carry out several complex analyses.

Chapter 4: Experimental Procedure

4.1 Research Questions

The following two questions are asked by this study:

1- *What level of rigor is appropriate for 9-11th grades for Reverse Engineering Units?*

2- *What is the best progression of high school Reverse Engineering activities, with a goal to build up to the skills to the Generator Flashlight Reverse Engineering Project in the Engineer Your World curriculum?*

4.2 Discussion of Research Questions

The first question is to address rigor for the high school underclassmen. Lessons available on the internet are mostly elementary and middle school level, and high school lessons available are not nearly as rigorous as the Engineer Your World Reverse Engineering Unit the author is using for seniors. This study will test higher rigor reverse engineering lessons to try to find the appropriate level for underclassmen.

The second question then addresses the progression of the activities so that the underclassmen are not overwhelmed by the more difficult topics. After seeing the activities in different situations through the years, students will easily assimilate them and develop a deeper conceptual understanding.

4.3 Engineering at Victoria West High School

The author of this report is using the Engineer Your World curriculum, written by University of Texas at Austin, for the senior engineering course at Victoria West High School, Victoria, TX. It is by far the most rigorous and all-encompassing high school Reverse Engineering Unit available (from an internet search and the author's experience with various curriculums). The only exception might be other proprietary curriculum that is unavailable for review, although even that is unlikely.

The progression of engineering courses at Victoria West High School has been:

First Year 2010/11: Introduced one engineering course:

Engineering Design and Problem Solving -12th graders

Fifth Year 2014/15: Five engineering courses will be offered (9-12 grades)

Concepts of Engineering (9^{th}-10^{th} graders)

Robotics (10^{th} graders)

Rocketry (11^{th} graders)

Engineering Math (11^{th}-12^{th} graders)

Engineering Design and Problem Solving (12^{th} graders)

This exponential growth of engineering courses at Victoria West has been exciting and challenging. The biggest challenge has been in the area of developing/purchasing curriculum (preferably project-based) for these new courses. The State of Texas only just approved these courses for high school four years ago, so companies, universities, and schools have been scrambling to write curriculum. An internet search for various engineering lessons today would hardly be recognizable to the paltry pickings one would have found four years ago. On the other hand, most of what is available today is for elementary and middle school level, and would need additional rigor added for high school.

Of particular priority for Victoria West is the Concepts of Engineering Curriculum. There is not a suitable off the shelf, project based curriculum, although new material may be available sometime in the future. Knowing that some of the same students that start as a freshman in Concepts of Engineering will proceed through the courses and end up in Engineering Design and Problem Solving as a senior, Victoria West would like to incorporate a progression of Reverse Engineering lessons throughout the lower level engineering courses offered.

4.4 Strengths of Reverse Engineering Lessons

The reasons that Reverse Engineering lessons have been identified as high value and desired as a progression through the courses are the inherit strengths associated with it:

1) It is a high interest, hands on activity.
2) It can be a segway to math, physics and engineering principles.
3) It inherently teaches the Engineering Design Process (albeit backwards) through Black Box Modeling, Affinity Analysis, and many more activities.
4) It fosters innovation by having students analyze designs, which may inspire them for future design projects.
5) Reverse Engineering written reports can be co-curricular, and therefore support the writing initiatives that Victoria West (and many Texas high schools) struggle with in light of the rigorous state STAAR tests.

4.5 Methodology

For this study, reverse engineering lessons were presented to several student groups. Student and teacher questionnaires were administered after the lesson to gather data for the research. The data was then analyzed to make recommendations for future reverse engineering lessons.

4.6 Choosing the Devices

The devices for the study were chosen from the following criteria in order of importance:

1- Minimal cost, preferably $2.99 or below, or a total of $32.89 for a class set of 11 (or $65.78 for 22 devices, if every student gets one to show the persons they interview.)
2- Disassembly/reassembly is that can be accomplished in one 50 minute class period so that open devices don't have to be left out overnight.
3- The highest complexity devices.
4- High interest devices.

The vendor of choice was Goodwill Industries since they sell working used small appliances for a fraction of the usual cost. For example, used hair dryers and mixers at Goodwill are $2.99. Other discount stores like Walmart or dollar stores will charge at least $15-20 for a hair dryer or mixer. The Goodwill Clearing House sells vacuums (mostly stick or hand vacs) and drills at for $2.99, but they are more expensive at regular Goodwill stores.

If cost of the device is the critical path, and Goodwill is the vendor of choice, then the devices have to be limited to what Goodwill has to offer. They have a seemingly endless supply of used hair dryers and mixers at a reasonable cost, so these two devices were used for this study. Note also that they sell used stick or hand vacuums; however, they can be more expensive and have a messy side effect: they are dirty. It is impossible to get the bags clean enough for classroom use, and the dust and smell permeated the classroom for days. Hand vacuums should be purchased new if they are to be used in the classroom.

Other devices Goodwill typically sells are appropriate for reverse engineering lessons and includes regular flashlights, hand sewing machines, toys, scales (bathroom and kitchen), mini fans, and various hand choppers. These devices were not used in this study because some are more expensive, and, more importantly, they are not available in class sets. They could be used if each student group does not need to have the same device.

Simple devices typically sold at Goodwill stores used in other reverse engineering lessons include can openers, wine openers, and tongs. These devices are plentiful in the stores, but do not offer the level of rigor needed. They could, however, be used as an introductory reverse engineering lesson to be completed at the end of a unit on gears or simple machines and require a less rigorous written report. The focus could be on the mechanical aspect and less on the Engineering Design Process.

4.7 List of Elements of Reverse Engineering Lessons

On the next page is a comprehensive list of possible elements of reverse engineering lessons from the internet and the author's experience with various curriculums. The items marked with an "x" were chosen for this study, based on a high level of rigor, time allotment, cross-curricular potential with English skills, and progression to senior EYW course. The written report was typed, including graphics except for hand sketches. Five Microsoft Word templates were given to the students to accelerate the report. If a student didn't type the report, the highest grade achievable was 70.

Table 4.1 Elements of Reverse Engineering Lessons

	Possible List of Elements of a Reverse Engineering Lesson (Some or all may be included in a Written Report)	**This Study May 2014**	**This Study: Included in Written Report**
E1	Device Choice: See section 4.6	Hair Dryer, Mixer, Vacuum	x
	Writing Opportunities:		
E2	Design Challenge – describe the challenge	x	x
E3	Description of Product – describe the original product	x	x
E4	Describe the device using the 9 Principles of Design (Balance, Emphasis, Movement, Pattern, Repetition, Proportion, Rhythm, Variety, Unity)		
E5	Summary of Research – describe the research and how it will affect the redesign		
E6	Disassembly Process – describe the steps, noting the suprises and difficulties	x	x
E7	Discussion of Pre/Post Sketches – compare and contrast the two sketches	x	x
E8	How does electricity flow?	x	x
E9	How does the device operate? Include the six simple machines.	x	x
E10	Redesign Description – describe the Redesigned device	x	x
E11	Next Steps – what would be the next steps (prototype, testing, cost analysis, etc.)		
E12	Describe your Redesign using the 9 Principles of Design (see #4 above)		
E13	Discussion of Professional, Ethical, and Safety Issues of the Redesign		
E14	Target Market - age, gender, uses of product, etc.	x	x
	Other Documents:		
E15	Visual Analysis – analyze the original device visually		

Table 4.1 Elements of Reverse Engineering Lessons (cont.)

	Possible List of Elements of a Reverse Engineering Lesson (Some or all may be included in a Written Report)	**This Study May 2014**	**This Study: Included in Written Report**
E16	Parts List – after disassembly list the name the parts and give material of construction	x	x
E17	Cell phone camera pictures of disassembly	x	
E18	Vocabulary	x	
E19	List of Redesign Features – list the features of the Redesign	x	x
E20	Cost Analysis of the Redesign vs. the Original		
E21	Engineering Design Process vs. Reverse Engineering Process	x	
	Drawings:		
E22	Predictive sketch – guess and sketch the internals of the device before disassembly	x	x
E23	Actual sketch – after disassembly	x	x
E24	Concept Sketching (C-Sketching) – Each student draws 3 ideas for Redesign, then they switch papers and add comments	x	
E25	Redesign Sketch	x	x
E26	Redesign Technical Drawing		
E27	Exploded View of Disassembled Device		
E28	Advertisement for Redesign		
E29	Hand sketches vs. Autocad, Sketchup, etc.		
E30	Isometric and Orthographic views		
	Research:		
E31	Competing Device Research	x	x
	Redesign Activities:		
E33	Black box modeling	x	x
E33	Energy Flow Diagrams	x	x
E34	Function Tree		
E35	Fishbone diagram		
E36	Activity Diagrams	x	x
E37	User Action Table		
E38	Interviews	x	x
E39	Affinity Analysis	x	

Table 4.1 Elements of Reverse Engineering Lessons (cont.)

	Possible List of Elements of a Reverse Engineering Lesson (Some or all may be included in a Written Report)	**This Study May 2014**	**This Study: Included in Written Report**
E41	Needs-Metrics Table		
E42	Benchmarking		
E43	Product Specifications		
E44	Brainstorming	x	
E45	Mind Mapping		
E46	C-Sketching	x	
E47	Gallery Walk		
E48	Pugh Chart		
E49	Redesign a design flaw of a product		
E50	Construct a physical prototype of a Redesign		
E51	Use the website: http://www.designwell.me/		
	Team Work:		
E52	Personality Testing	x	
E53	Homo/Heter grouping	x	
E54	Team and Peer Feedback		
E55	Ghantt chart or other means of project mgmt		
	Activites:		
E56	Pre-Exploration Period to operate the device	x	
E57	Disassembly/Reassembly	x	
E58	Reassemble to operate differently (toy to go backwards)		
E59	Class Presentation		
E60	Draw Redesigns on the board and discuss		
E61	Use math and science equations to model a device		
E62	Reverse Engineering Showcase (like a science fair)		
E63	After disassembly, attach parts on a display board and identify		
	Engineering Notebooks:		
E64	Engineering Packet (with worksheets stapled for fill in)		

Table 4.1 Elements of Reverse Engineering Lessons (cont.)

	Possible List of Elements of a Reverse Engineering Lesson (Some or all may be included in a Written Report)	**This Study May 2014**	**This Study: Included in Written Report**
E66	Full Engineering Notebook (students keeps notes and then writes final report from notes)		
	Written Report:		
E67	Completed in Teams		
E68	Completed by Individuals	x	
E69	Includes any combination of elements listed above	x	
E70	Use of Word, Excel, Powerpoint, and Autocad type programs	x	

4.8 Goal Chart for Reverse Engineering Lesson:

The goals for the lesson include choice of device, length of the lesson, and Redesign activities.

Table 4.2 Goal Chart for Reverse Engineering Lessons

	Elements	Goal	Ways to Achieve (see section 4.7)
G1	High Student Interest	Choice of device: 1-use toys 2-consider gender (hair dryer for girls) 3-offer three choices per class (hair dryer, mixer, drill) 4-More complex – drill, mixer Disassembly process	E1 E57
G2	Engineering Design Process (or Reverse Engineering Process)	All activities show an aspect of the design process, use more of them for a richer experience	E2 thru E69
G3	Foster Innovation	All design activities, especially sketching and disassembly Use the website: http://www.designwell.me/	E2 thru E65
G4	Drawing skills	Pre-Sketch, Post-Sketch, C-sketching, Redesign Sketch	E22 thru E30
G5	3D Spatial Skills	All 4 Sketches, Disassembly, Interviews, Black Box Model, Energy Flow Diagram, Description of Components (How does electricity flow, How do the gears work), Redesign	E22 thru E30
G6	Customer Needs Skills	Interviews, Affinity Analyis	E38 E39
G7	Encourage Curiosity for how things operate	Pre and Post Sketches, disassembly, redesign	E22 E23 E57
G8	Science knowledge and	Written assignment on How the Device Operates, How Electricity	E8 E9

Table 4.2 Goal Chart for Reverse Engineering Lessons (cont.)

	Elements	Goal	Ways to Achieve (see section 4.7)
G9	Experience with long reports	Require a long report for a grade for each individual	E67 thru E69
G10	Autocad and Sketchup –type program skills	Require drawings to be completed by these programs.	E69
G11	Word/Excel Skills	Require the report to be typed.	E69
G12	Writing skills, esp. 9th and 10th to assist with State Tests	Written assignments (see list in Element Table)	E2 thru E14
G13	Teamwork	Personality tests with grouping, Team and Peer Feedback, Team Assignment Logs	E52thru E55

4.9 Device and Class Schedule

Six classes participated in the study, ranging from freshman to seniors. The devices used include generator flashlights, hand and stick vacuums, hair dryers, electric hand mixers, plastic manual hand mixers, and drills.

Table 4.3 Device and Class Schedule

Class Period	Grades	Device	Previous Experience with Engineering
1	11,12	Flashlight	This class had completed the EYW curriculum, incl. Flashlight Reverse Engineering.
2	9	Vacuum	**
3	9,10	Hair Dryer	**
5	9	Plastic Hand Mixer	None (this is a remedial math class)
6	9,10	Electric Hand Mixer	**
7	11	Drill	This is a Rocketry class.

** These classes had completed these Engineering projects: Stick and Clay Shelters, Marble Grippers, Model of Hand, Water Bottle Rockets, Rubber Band Airplanes, Complex Machines

4.10 Experimental Plan

1- Choose a different device for each class.
2- Implement the Reverse Engineering Lesson Plan.
3- Administer the student questionnaires.
4- Administer the teacher questionnaire.
5- Analyze the results of the student and teacher questionnaires to see if the students liked the lesson and what suggestions they have for improvement.

Chapter 5: Results and Recommendations

5.1 Teacher Questionnaire Results

The Recommendations will be based, in part, on the findings in this table.

Table 5.1 Teacher Questionnaire Results

	Disagree →				Agree	Totals
Statements	**1**	**2**	**3**	**4**	**5**	
The students were engaged.					x	5
The level of rigor was appropriate.				x		4
The lesson was completed on time.					x	5
The students completed the lesson as inquiry with minimal supervision.				x		4
There were math and science concepts needed to complete the lesson.				x		4
					Avg	4.4

The teacher (the author of this report) thought that the lessons went very well and that student engagement was high. The three categories that received 4s instead of 5s were due to the typical struggle of students with rigor and completing assignments. It is a fine line between ensuring rigor and pushing students too hard, and making sure all aspects of assignments have value and are not just time consuming busy work.

5.2 Teacher Comments

Table 5.2 Teacher Comments

Areas of Concern	Positive Areas
Lack Word/Excel Skills	Report Helps Develop Skills
Less Experience with Long Reports, Somewhat overwhelmed	Supplied 5 Word Document Templates as a starting place
Writing Skills Underdeveloped	Report Helps Develop Skills
Less Background in Physics/Engr	Need Pre-teaching for Physics topics
Device choice can help engagement	Classroom management not an issue with disassembly/reassembly
Low Writing Scores on Texas STAAR Tests	Writing the report is co-curricular and will help with writing scores
Too many activities (Black Box, etc.) dilute the retention	Pick and choose carefully the extra activities

Again, we must balance the rigor and difficulty of teaching new skills with the possibility of overwhelming the students. One way to compromise is to scaffold, such as giving students the word templates for parts of the report, work on parts of the report together in class, give free periods to work on the report with teacher circulating for assistance. Another idea would be to have the students work on the report together, sharing materials. For this study, the report was the student's Final and was 15% of the grade, so each student completed the report individually.

5.3 Student Questionnaire Results

The Recommendations will be based, in part, on the findings in this table. The numbers indicate how many responses were received for each column.

Table 5.3 Student Questionnaire Results

	Disagree →				Agree	Avg
Statements	**1**	**2**	**3**	**4**	**5**	
I enjoyed this lesson.	3		11	11	34	4.2
I liked the device I was given.	1			9	47	4.8
I understood all the activities in this lesson.		2	19	12	13	3.8
I had the right amount of assistance to complete the activities.			4	16	38	4.6
I have a good understanding of Reverse Engineering after completing this lesson.		4	7	3	42	4.5
The written report was a appropriate length for this lesson.	23	13	4	6	9	2.4
					Avg	4.1

Two areas of concern to the students were the activities and the written report. The activities consisted of Black Box Model, Activity Diagram, Research, User Action Table, and more (see Appendix 1). To teach these activities, partners did one example and then shared with the class, and then partners worked on the activity for their product, which would become part of the report. For younger students, this may not have been enough exposure for them to feel like they had a good understanding. So the question is whether to pare back the number of activities and go into more depth, or to keep the high number of activities and accept a cursory overview. Students that take more engineering courses will see these activities again and will gain a deeper understanding at that time. This latter approach is better, since there will be some high level students that will gain more understanding, and the lower students will at least have seen the activities, and their grade will not suffer since they have sufficient help with the activities.

The written report was another concern for the younger students. It was quite possibly the first time they had to complete a report of this magnitude, typed, with word processing, clip art, scanning, and excel skills. Some griping is to be expected, but not catered to. It is best for students to learn these skills in the introductory course, because they will use them throughout the rest of the engineering courses. Ideas for scaffolding as listed in Section 5.2 above, would also help alleviate the concerns but not entirely.

5.4 Student Comments

Table 5.4 Student Comments

Areas of Concern	Positive Areas
Written Report too much work	Its fun to take things apart
I didn't understand all the activities	I like to pick the features for redesign
It counted as my Final grade	I like hands on

These comments mirror the results in Section 5.3, and reiterate the disdain for the written report, and the enthusiasm for the hands on activities.

5.5 Recommendations:

The progression of reverse engineering activities from freshman to senior level is best accomplished by a wide approach. Freshman should be exposed to as many activities as there is time for, and grading should be lenient, possibly as completion grades instead of content grades. They can also work in groups, so they can collaborate. This will give the younger students more experience with the ideas applied to the different devices in each grade level.

Report writing skills should be scaffolded but not compromised in the younger grades. The time spent in class teaching freshman word processing, spreadsheets, report format, researching, and file management such as email, thumb drives, and file sharing will be well worth it in the upper level courses. If upper level teachers do not have to spend time on these skills, they will be able to cover more high level engineering material.

Also, preteaching the applicable physics concepts such as electricity, motors, gears, and springs will help the freshman to understand and feel confident in their reverse engineering activities. Without these pretaught skills, an opportunity for discovery and understanding is forever lost when the device is opened and studied.

The decision as to whether to work in groups or as individuals is another opportunity to increase rigor and workload, for all groups, but especially the younger students.

Table 5.5 Recommendations

Grade Device Additional Skills Preteaching Report

Grade	Device	Additional Skills	Preteaching	Report
9-10	#1: Small push, cam or windup Toy	Use as a Project Grade: Predrawing, Actual Drawing, Parts List, Redesign drawing and description	Classroom Management: Emphasize to reassemble, use paper plates and proper tools "Mini" Engineering Notebook –stapled pages with fill-ins	Turn in "Mini" Engineering Notebook as done mostly together in class
9-10	#2: Hair Dryer	Use as Final Grade: Black Box, Energy Flow, Interviewing, C-sketching, technical drawing	Use "Mini" Engineering Notebook w/o fill-ins, some pages done together in class	Typed Report – give Word Templates
11	Mixer	Use as a Test Grade: Black Box, Energy Flow, Interviewing, C-sketching, technical drawing	Engineering Notebook Gears Electricity/Motors Switches, Springs	Typed Report
12 EYW	Pig Flashlight	Functional modeling: black box modeling, energy flow diagrams, and function trees Activity diagrams – user actions Design requirements: interviewing, affinity analysis, creating needs-metrics tables, Benchmarking, product specs Concept generation – mind-mapping, C-sketching, Pugh chart, Technical report	Instrumentation and experimentation Data acquisition, analysis and representation Techniques for concept generation Design embodiment – technical drawing Verifying performance Engineering notebooks	Typed Report

5.6 Additional Considerations:

1- Time Allotted for the RE Lesson:

Reverse Engineering lessons can be completed in one class period or over a six week unit. It depends on the goals of the teacher, the TEKS for the course, and how much time is allotted. The Engineer Your World Reverse Engineering Unit is a multi-week unit and is the most comprehensive known. However, the internet abounds with 1,2, and 3 day lessons that use various elements to accomplish varying goals.

2- The Interviews (Element E38) normally would be accomplished by each student taking the device home and interviewing friends and relatives about their opinion of that particular device. This requires a one to one ratio of device to student for this activity, and for the students to be responsible to do the interviews and bring the device back to class. This study took a different approach. The interviews were done without taking the devices home, and the questions were about the type of device in general, instead of that particular device. Some details of the Redesign process are lost by this approach, but the benefits include that it limits the number of devices that need to be purchased, and accounts for freshman students who might not be responsible to bring the devices back intact, and accomplishes the interviews overnight.

5.7 Next Steps:

1. Consider ways to address the results of the student survey and the concerns about the knowledge of the activities and the written report. Look at reducing the number of activities to afford deeper understanding. Then allow for the progression of activities, adding

more each year to culminate in the Engineer Your World Senior Reverse Engineering project.

2. Also look at ways to scaffold the skills needed for the written report, including word processing, spreadsheet, research, and file management including email, USB (thumb) drive, and file sharing.
3. Contact the management of Goodwill Industries, Walmart, or other discount stores to see if they would be willing to donate or discount devices for Reverse Engineering lessons.
4. Email the school district employees to see if they will save their cast-off/broken devices to donate to the engineering courses.
5. Continue to implement and tweak the reverse engineering lessons for the underclassmen at Victoria West High School, including the new Engineering Math class for the fall 2014.
6. As the underclassmen students become seniors and take the Engineer Your World course, continue to be cognizant if they are ready for the senior reverse engineering unit.

Appendix 1: Student Artifacts

A1.1 Table of Contents

Concepts of Engineering

Reverse Engineering of a Mixer

Name: xxxxxxxx Product: Mixer Period: 6 Date: 6-4-14

Table of Contents

15 16 17 18	Discussion of Before/After Sketches How does electricity flow How does the device operate
19 20 21	Redesign Description List of Features Hand sketch
22 23 24	Target Market Age Gender Uses of product

A1.2 Design Challenge

The Design Challenge

I work for a mixer manufacturer that is losing market share to a competitor. My supervisor assigned my team this task:

"Understand how the competitor's mixer works, come up with ways to improve it, and propose a redesign that we can manufacture and market to put our company back on top."

A1.3 Description of Product

Description of Product

A mixer seems to be a very basic piece of technology. That is true to a certain extent. To use the machine, put the beaters in their designated spots on the front of the mixer, and plug the cord into the wall outlet. Next, the power would be activated as the speed is set since the speed setting works for a dual purpose. The mixer's beaters will spin rapidly or slowly, depending on the speed setting. Once the contents in a container are mixed, eject the beater to clean and store the mixer. The mixer has fairly simple functions and actions; it is also build in a noncomplex way. A mixer has two metal mixers, a hard plastic shell covering, a fan, two gears with 42 teeth each, one worm gear with 10 teeth each, two compression springs to work along with the ejection button, the beater spin speed dial, a cord, and the motor that generates electricity from the cord plugged in the outlet. The only features on the basic mixer are the fact that it is hand held, dual rotatory beaters, and speed control. According to many users of the mixer, those features are not suitable for their needs.

A1.4 Interview

Interview Sheet

Customer Age: 15 Gender: female Occupation: Student Product: Mixer [redacted]

Question	Customer Answer	Importance
How would you typically use a mixer?	make cookie dough	not very
What do you like about it?	speeds process	very
What do you dislike about it?	takes joy out of hand making things	super very
Do you have any suggestions for improvement?	make them quieter	double very
What are the best features of a mixer?	Speed changes	very
What other features would you like to see on a mixer?	Cover to protect from splattering	very

A1.5 Background Research

Reverse Engineering

Background Research

Name: xxxxxxxx

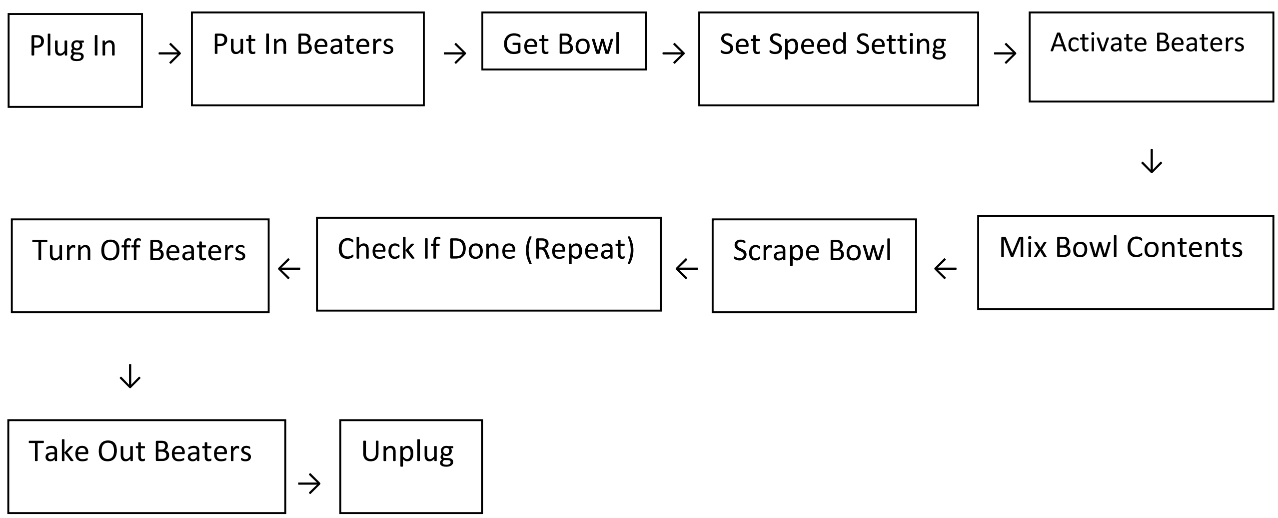
Competitors	Price	Features
KitchenAid -5 Speed Ultra Power hand Mixer	$49.99	5 Speeds, Lockable Swivel Cord, Beater Ejection Button, Stainless Steel Turbo Beater Accessories, Multiple Colors
Hamilton Beach -6 Speed Hand Mixer	$21.99	Power Boost, Beater Ejection Button, Bowl Rest
Breville -Handy Mix Digital	$79.99	5 Foot Power Cord, Turbo Button, Nonskid Feet, 16 Speeds with a Speed Menu, 200 Watts Maximum
Cuisinart -Power Advantage Hand Mixer	$49.95	Multiple Colors, Easy to Use Speed Control, Beater Ejection Lever, Swivel Cord for Right or Left Handed, Extra Long Self Cleaning beaters with no Center Post

List Uses of Device:

1- Whisking
2- Mixing Cake Batter
3- Whipping Cream
4- Mashing Potatoes
5- Mixing Bread Batter
6- Stirring
7- Mixing Cookie Batter
8- Beating Eggs

A1.6 Activity Diagram

Activity Diagram



A1.7 User Action Table

User Action Table

Product: Mixer

Name: xxxxxx

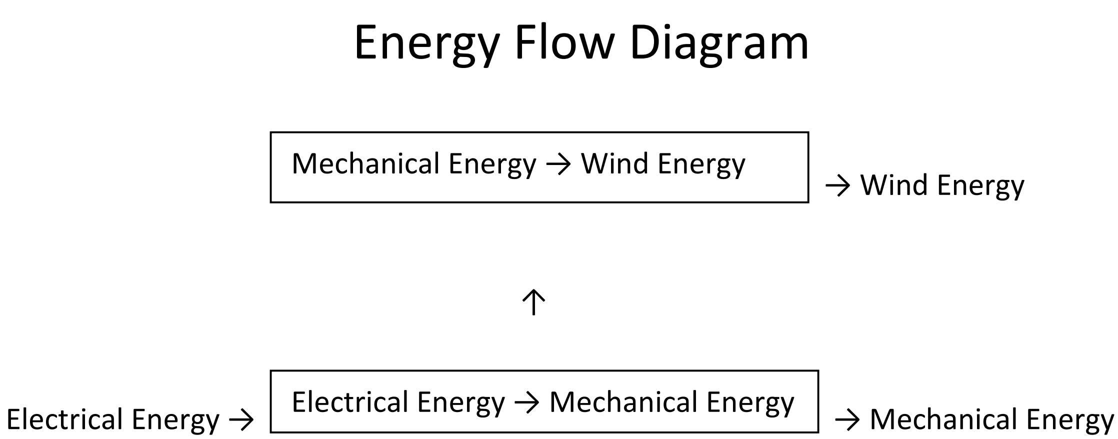
User Action Product Function Redesign

Opportunity

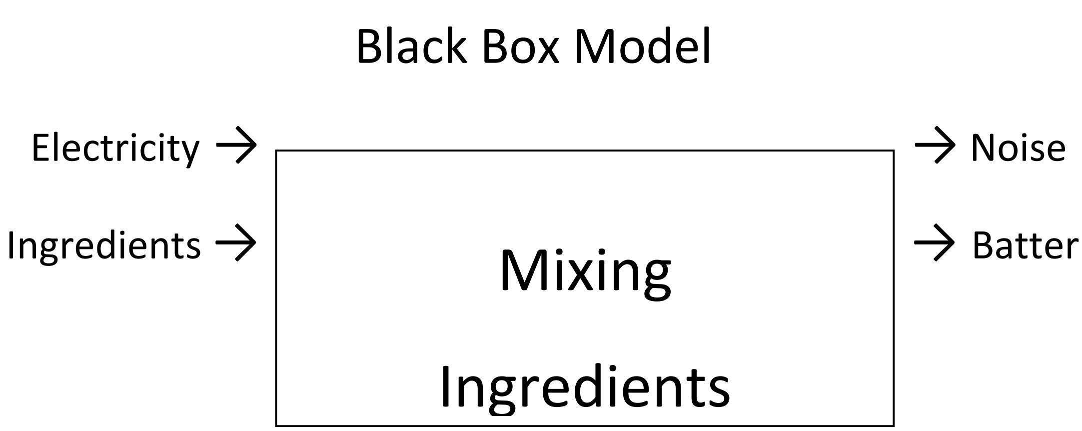
Pick up	Accept hand	Rubber outer material, strap
Plug in	Get power	Battery, Retractable cord
Put beaters in	Attach to mixer	Arched Beaters
Get bowl	Accept bowl in hand, put bowl under mixer	Attach bowl to mixer
Set speed setting	Turn dial	Automatic timer
Activate beaters	Churn/ mix content	On/ off button
Mix bowl contents	Mix things in bowl, beaters turn	Different attachments to accommodate texture of contents
Scrape bowl	Get contents off side of bowl	Spatula-like attachment

Check if done (repeat if necessary)	Remove beaters from bowl	Different attachments to check readiness
Turn off beaters	Stop mixing	On/ off button
Take out beaters	Remove beaters from mixer	Easy eject button
Unplug	Cut off power	Battery, Retractable cord

A1.8 Energy Flow Diagram



A1.9 Black Box Model



Hand Energy → → Heat

Air → → Air

A1.10 Discussion of Disassembly

Product Disassembly: Discussion of Process

As expected of any good engineer, we, the students, were instructed to draw a diagram of what we thought was inside the mixer that made it work. My diagram displayed a motor, an electrical wire to connect the motor with the power cord that plugged into the outlet, and an ejection system. The ejection system worked when the eject button was pushed and it, in turn, pushed the beater rods out of the holes they were attached to. As I began the disassembly process, I began to see that the inside components we more complex than I originally anticipated. I started by unscrewing three screws to open the plastic outer shell. Inside, there were multiple wires. The wires connected the speed control dial to the motor and the motor to the cord plugged that was used to plug into the outlet. The motor was compiled in a ball of wires, and it controlled every movement in the system. The gears to make the beaters move were attached to the motor. One beater was attached to a regular 42-toothed gear, and the other beater was attached o another 42-toothed gear. There was a 10-toothed worm gear between the other two gears to keep the beaters spinning and going the same direction. A fan was also inside to keep the motor cool. The eject button was attached to posts; linear to the beater rods. There were compression springs coiled around the posts to keep the post from always making contact with the beater rods. All of the pieces inside the mixer were connected to each other in one way or another to create a functioning food mixer.

A1.11 Parts List

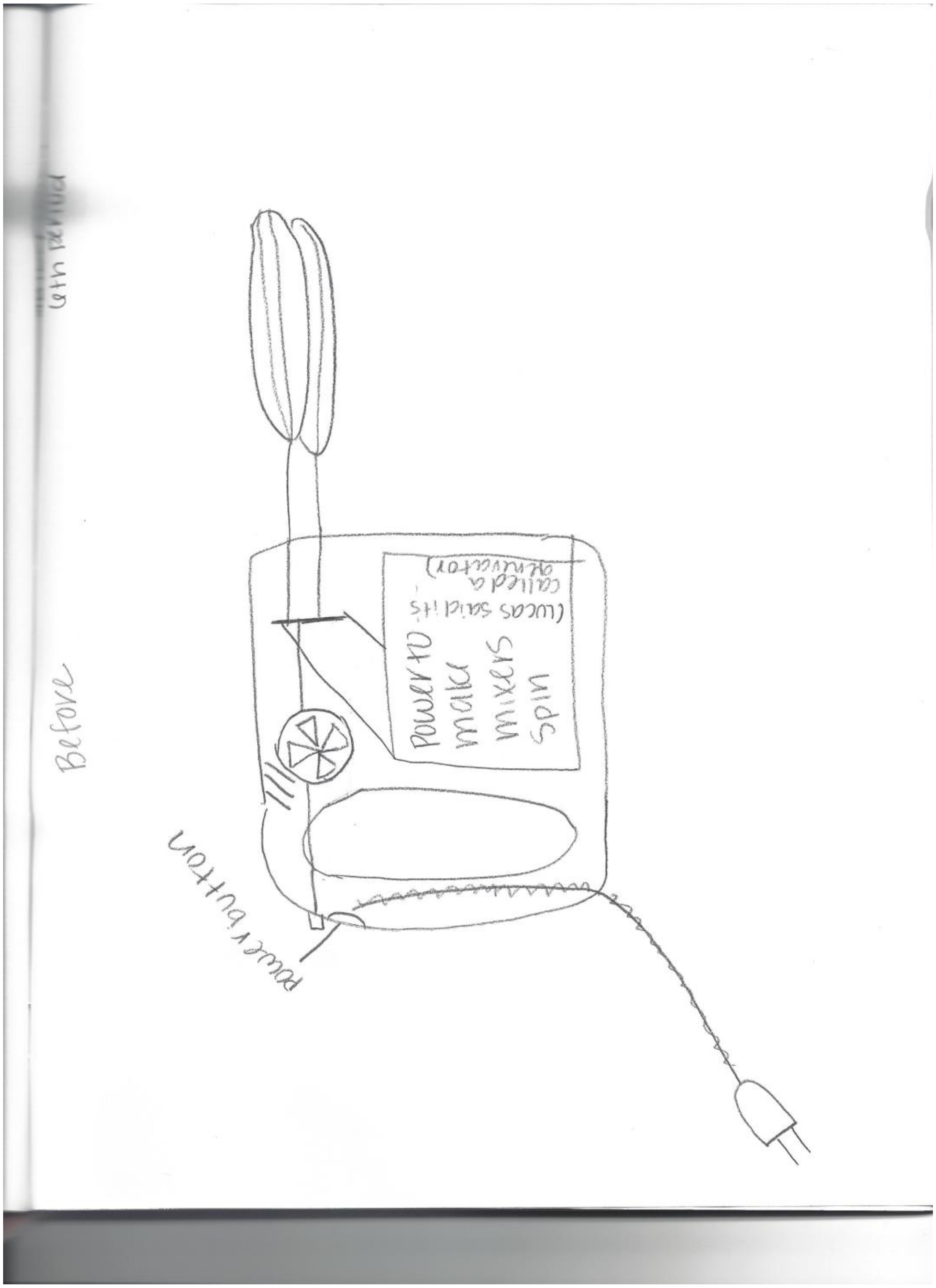
Name: xxxxxxx

Product Disassembled: Mixer

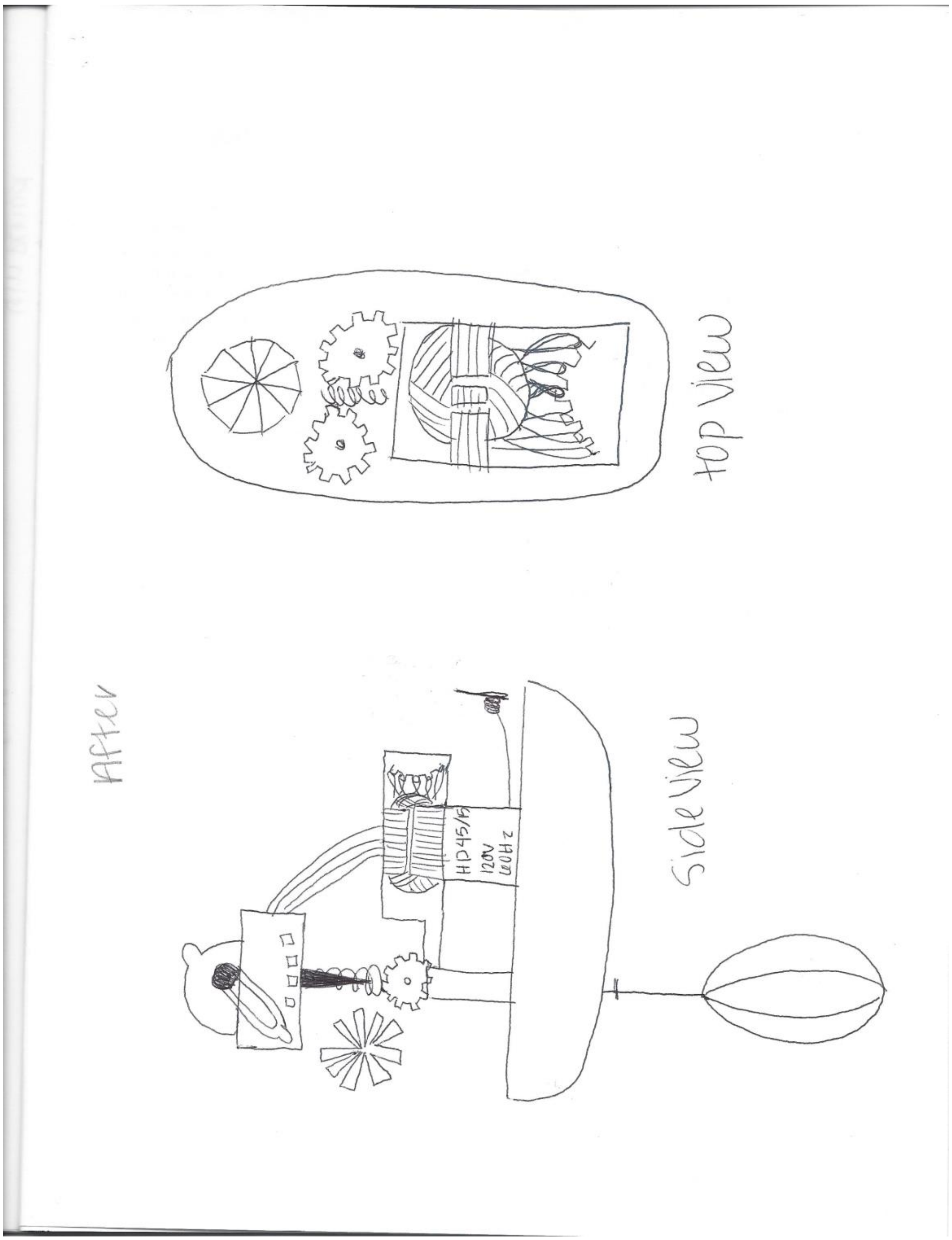
Part Number Part Material

1	Slide Switch	Plastic
2	Button	Plastic
3	Gears (2) 43 teeth	Plastic
4	Worm Gear 10 teeth	Metal
5	Copper Wires	Copper
6	Insulated Wires	Rubber and Copper
7	Motor	Metal and Plastic
8	Fan	Plastic
9	Compression Springs (2)	Metal

A1.12 Hand Sketch before Disassembly



A1.13 Hand Sketch After Disassembly



A1.14 Before and After Sketches Discussion

Before and After Hand Sketches Discussion

During reverse engineering, it is important to understand for yourself how something works before physically seeing it work. I attempted to predict what the inside of the mixer would look like. I started by finding my power source. I knew the cord that plugged into an outlet had to be connected to something. I discovered that the electric energy would be transformed into mechanical energy inside of a motor. Although I knew there was a motor, I was unsure of the components of it. Also, there had to be an ejection system for the beaters to be removed. My system consisted of a button connected to a pole that had a flat piece attached at the end to force the beater rods out. My diagram included a connection between the motor and the beaters for the power to spin and a fan in order to keep the motor cool. Lastly, I included a connection between the motor and the speed control in order to change the speed according to preference. Once opened, I realized the mixer was much more complex than my original diagram. The fan placed near the top to keep the entire machine cool. The motor was composed of multiple wires that connected the speed control dial to the motor. Multiple wires also connected the exterior plug and cord to the motor. Two 2-toothed gears and a 10-toothed worm gear were powered by the motor. The two individual beaters attached to each of the regular gears. The worm gear was used to rotate the beaters and have them going in the same direction. The ejection system was much more clever as well. The eject button was connected to two posts that in turn sat linear to the two beater rods. There were compression springs to prevent the posts from constant contact with the beater rods. The only time there was physical contact with the beater rods was when the eject button was pushed to force the spring to compress and the rods to come out of the holders.

A1.15 How Does Energy Flow?

How Does Energy Flow?

Energy flows through a conductor, and in order for energy to be available for the conductor to carry it, there has to be a power source. In the mixer's case, the power source is the electricity coming from the wall outlet and the conductor is the wires that transmit energy to the motor. From there, the motor sends electricity to other parts of the mixer. The electrical energy from the wall will transmit into mechanical energy and through the copper wires to the fan and gears that turns the beaters. When the mechanical energy reaches these items, the fan and the beaters begin to move. The mechanical energy will also transform into wind energy when the fan begins to put off wind as it moves.

A1.16 How Does the Device Work?

How Does the Device Work?

This device is easy to operate, but the functions are a little more difficult to understand. When the cord is plugged into the wall, the electrical energy is transferred to the motor. The motor is where the mechanical energy is formed to create movement in the beaters and the fan. When the speed is set, the gears that move the beaters are triggered and the energy from the motor is put into action. The beaters start to turn at a set rate. The same thing happens to the fan. When the fan is triggered or is needed, the energy will power the fan to spin. When the mixing is finished, the speed dial is turned off and that cuts of the power supply with the gears turning the beaters. When the beaters get ejected, there is a button to push that is attached to two posts coiled in compression springs. When the button is pressed, the spring compresses and the posts push and force the beater rods forward, making them eject from the holders. Once the cord and plug are taken out of the outlet, the power supply is gone and the device can no longer function on its own.

A1.17 Redesign Description

Redesign

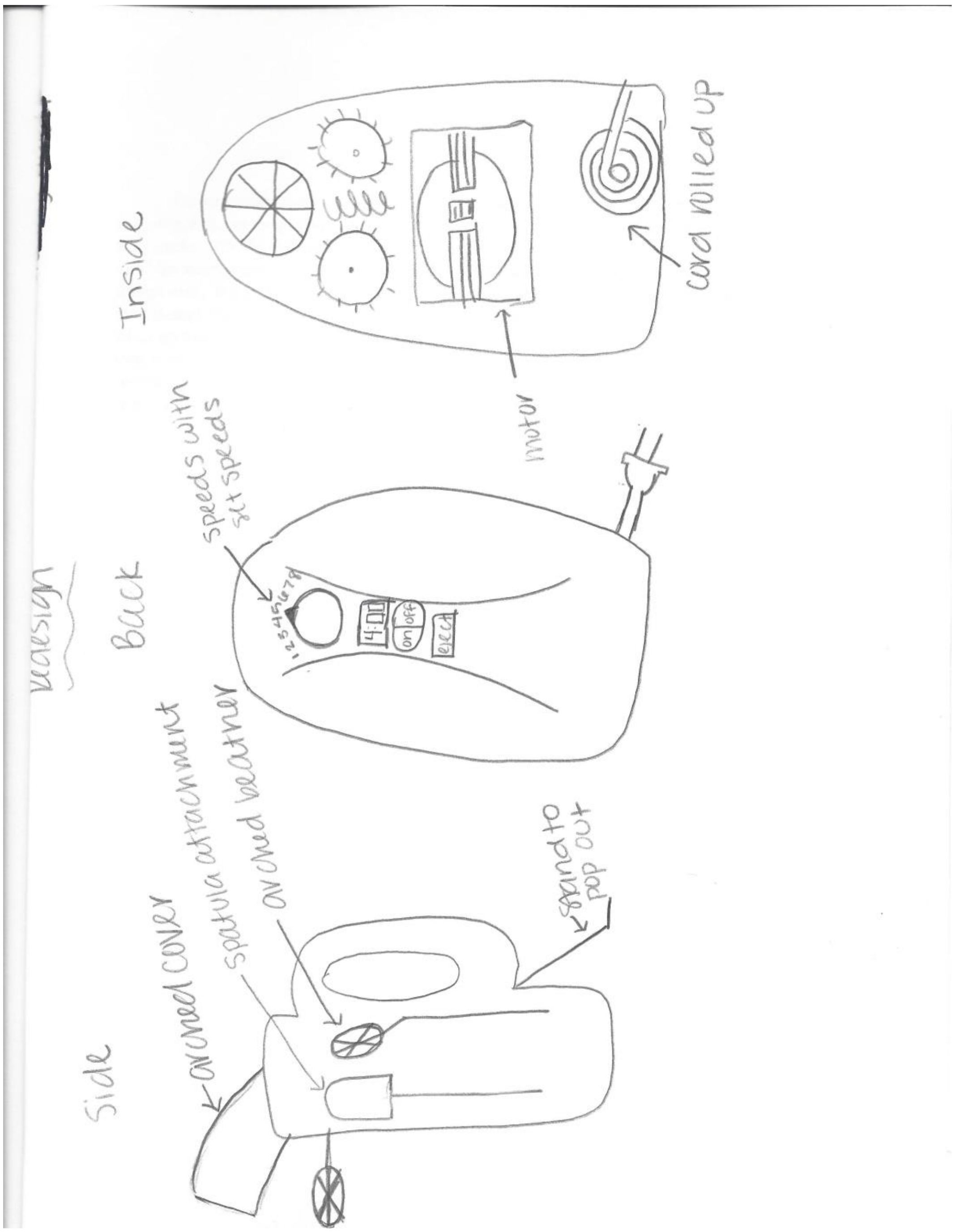
Description: After careful consideration and research, I've discovered the users of mixers feel that there are some features absent in the functions. Among one of the biggest problems is the cord. It is always tangled and is very hard to store. My solution is to add a retractable cord. A retractable cord would save a lot of hassle and a lot of time. The redesign will have different attachments that will go in the duel beater holders. The attachments include two beaters, two spatulas, or two arched beaters. These various attachments will help mix differently textured foods. Another redesigned feature is an arched cover to prevent a splattering mess. This cover will be angled at a certain degree to cover over the beaters to shield from any pieces of the mixture escaping the bowl. In addition, a stand, similar to one a bicycle might have, would be added to the bottom in the back of the machine for support so the mixer will not tip over if it is sat down on a counter. The redesign will also have 8 speeds; each having their own timer setting that will be displayed on the small screen. Lastly, the new mixer will have an on/off button and eject button.

Features:

- Arched cover for beaters
- Different attachments (spatulas, regular beaters, arched beaters)

- Standing support
- Retractable cord
- On/off button
- Eject button

A1.18 Hand Sketch of Redesign



A1.19 Target Market

Target Market

The targeted markets for this redesigned device are mothers and chefs. The ages are very vast and can range from 20 years old to 95 years old. This redesign will benefit anyone who cooks. Mostly, this device targets women because it is the “social standard” or “status quo” for women too cook. The uses of the product will not change much from its original design uses. It will still mix cake, cookie and brownie batters, mashed potatoes, whip cream, etc.; though the efficiency will increase. The different attachments will help accommodate to what texture of food is being mixed, and the timer will help the person cooking to know how long it takes for the mixing to be complete. In conclusion, this redesign did not completely remake everything known about the mixer; the redesign simply combined all the common complaints from mixer users and corrected the problems. The redesign is meant to attract and appeal to now buyers because of the new features.

Appendix 2: Texas High School Engineering Courses Requirements

A2.1 List of Courses

Texas offers six high school engineering courses (Texas Education Agency, 2010).

Section	Name of Texas Course	Victoria West
7.2	Concepts of Engineering and Technology	9-10th grade
7.3	Engineering Design and Presentation	Not offering
7.4	Advanced Engineering Design and Presentation	Not offering
7.5	Engineering Math	11-12th grade
7.6	Robotics and Automation	
7.7	Scientific Research and Design	Rocketry 11th grade
7.8	Engineering Design and Problem Solving	11-12th grade

A2.2 Concepts of Engineering and Technology

Chapter 130. Texas Essential Knowledge and Skills for Career and Technical Education

Subchapter O. Science, Technology, Engineering, and Mathematics

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Statutory Authority: The provisions of this Subchapter O issued under the Texas Education Code, §§7.102(c)(4), 28.002, 28.0022, and 28.025, unless otherwise noted.

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§130.361. Implementation of Texas Essential Knowledge and Skills for Science, Technology, Engineering, and Mathematics.

The provisions of this subchapter shall be implemented by school districts beginning with the 2010-2011 school year.

Source: The provisions of this §130.361 adopted to be effective August 23, 2010, 34 TexReg 5941.

§130.362. Concepts of Engineering and Technology (One-Half to One Credit).

(a) General requirements. This course is recommended for students in Grades 9-10.

(b) Introduction. Concepts of Engineering and Technology provides an overview of the various fields of science, technology, engineering, and mathematics and their interrelationships. Students will use a variety of computer hardware and software applications to complete assignments and projects. Upon completing this course, students will have an understanding of the various fields and will be able to make informed decisions regarding a coherent sequence of subsequent courses. Further, students will have worked on a design team to develop a product or system. Students will use multiple software applications to prepare and present course assignments.

(c) Knowledge and skills.

(1) The student investigates the components of engineering and technology systems. The student is expected to:

(A) investigate and report on the history of engineering science;

(B) identify the inputs, processes, and outputs associated with technological systems;

(C) describe the difference between open and closed systems;

(D) describe how technological systems interact to achieve common goals;

(E) compare and contrast engineering, science, and technology careers; and

(F) conduct and present research on emerging and innovative technology.

(2) The student presents conclusions, research findings, and designs using a variety of media throughout the course. The student is expected to:

(A) use clear and concise written, verbal, and visual communication techniques;

(B) maintain a design and computation engineering notebook;

(C) use sketching and computer-aided drafting and design to present ideas; and

(D) maintain a portfolio.

(3) The student uses appropriate tools and demonstrates safe work habits. The student is expected to:

(A) master relevant safety tests;

(B) follow safety guidelines as described in various manuals, instructions, and regulations;

(C) recognize the classification of hazardous materials and wastes;

(D) dispose of hazardous materials and wastes appropriately;

(E) perform maintenance and safely handle and store laboratory equipment;

(F) describe the implications of negligent or improper maintenance; and

(G) demonstrate the use of precision measuring instruments.

(4) The student describes the factors that affect the progression of technology and the potential intended and unintended consequences of technological advances. The student is expected to:

(A) describe how technology has affected individuals, societies, cultures, economies, and environments;

(B) describe how the development and use of technology influenced past events;

(C) describe how and why technology progresses; and

(D) predict possible changes caused by the advances of technology.

(5) The student describes the importance of teamwork, leadership, integrity, honesty, ethics, work habits, and organizational skills. The student is expected to:

(A) describe and demonstrate how teams function;

(B) identify characteristics of good team leaders and team members;

(C) work in a team face-to-face or in a virtual environment to solve problems;

(D) discuss the principles of ideation;

(E) identify employers' expectations and appropriate work habits;

(F) differentiate between discrimination, harassment, and equality;

(G) describe ethical behavior and decision making through use of examples;

(H) use time-management techniques to develop team schedules to meet project objectives; and

(I) complete projects according to established criteria.

(6) The student thinks critically and applies fundamental principles of system modeling and design to multiple design projects. The student is expected to:

(A) identify and describe the fundamental processes needed for a project, including design and prototype development;

(B) identify the chemical, mechanical, and physical properties of engineering materials;

(C) use problem-solving techniques to develop technological solutions;

(D) use consistent units for all measurements and computations; and

(E) assess risks and benefits of a design solution.

(7) The student understands the opportunities and careers in fields related to biotechnology. The student is expected to:

(A) describe the fields of biotechnology;

(B) describe career opportunities in biotechnology;

(C) apply design concepts to problems in biotechnology;

(D) identify fields related to biotechnology; and

(E) identify currently emerging issues in biotechnology.

(8) The student understands the opportunities and careers in fields related to process control and automation systems. The student is expected to:

(A) describe applications of process control and automation systems;

(B) describe career opportunities in process control and automation systems;

(C) apply design concepts to problems in process control and automation systems;

(D) identify fields related to process control and automation systems; and

(E) identify emerging issues in process control and automation systems.

(9) The student understands the opportunities and careers in fields related to physical and mechanical systems. The student is expected to:

(A) describe the applications of physical and mechanical systems;

(B) describe career opportunities in physical and mechanical systems;

(C) apply design concepts to problems in physical and mechanical systems; and

(D) identify emerging issues in physical and mechanical systems.

(10) The student participates in a team-based culminating project. The student is expected to:

(A) apply the design process in a team;

(B) assume different roles as a team member within the project;

(C) maintain an engineering notebook for the project;

(D) develop and test the model for the project; and

(E) present the project using clear and concise communication skills.

Source: The provisions of this §130.362 adopted to be effective August 23, 2010, 34 TexReg 5941.

A2.3 Engineering Design and Presentation

§130.365. Engineering Design and Presentation (One to Two Credits).

(a) General requirements. This course is recommended for students in Grades 10-12. Recommended prerequisite: Concepts of Engineering and Technology.

(b) Introduction. Students enrolled in this course will demonstrate knowledge and skills of the process of design as it applies to engineering fields using multiple software applications and tools necessary to produce and present working drawings, solid model renderings, and prototypes. Students will use a variety of computer hardware and software applications to complete assignments and projects. Through implementation of the design process, students will transfer advanced academic skills to component designs. Additionally, students explore career opportunities in engineering, technology, and drafting and what is required to gain and maintain employment in these areas.

(c) Knowledge and skills.

(1) The student gains knowledge of and demonstrates the skills necessary for success in the workplace. The student is expected to:

(A) distinguish the differences between an engineering technician, engineering technologist, and engineer;

(B) identify employment and career opportunities;

(C) investigate and work toward industry certifications;

(D) demonstrate the principles of teamwork related to engineering and technology;

(E) identify and use appropriate work habits;

(F) demonstrate knowledge related to governmental regulations, including health and safety;

(G) discuss ethical issues related to engineering and technology and incorporate proper ethics in submitted projects;

(H) demonstrate respect for diversity in the workplace;

(I) demonstrate appropriate actions and identify consequences relating to discrimination, harassment, and equality;

(J) demonstrate effective oral and written communication skills using a variety of software applications and media; and

(K) explore career preparation learning experiences, including, but not limited to, job shadowing, mentoring, and apprenticeship training.

(2) The student participates in team projects in various roles. The student is expected to:

(A) understand and discuss how teams function;

(B) use teamwork to solve problems; and

(C) serve as a team leader and a team member and demonstrate appropriate attitudes while participating in team projects.

(3) The student develops skills for managing a project. The student is expected to:

(A) use time-management techniques to develop and maintain work schedules and meet deadlines;

(B) complete work according to established criteria;

(C) participate in the organization and operation of a real or simulated engineering project; and

(D) develop a plan for production of an individual product.

(4) The student practices safe and proper work habits. The student is expected to:

(A) master relevant safety tests;

(B) follow safety guidelines as described in various manuals, instructions, and regulations;

(C) identify and classify hazardous materials and wastes according to Occupational Safety and Health Administration regulations;

(D) dispose of hazardous materials and wastes appropriately;

(E) perform maintenance on selected tools, equipment, and machines;

(F) handle and store tools and materials correctly; and

(G) describe the results of negligent or improper maintenance.

(5) The student applies the concepts of sketching and skills associated with computer-aided drafting and design. The student is expected to:

(A) sketch single- and multi-view projections;

(B) prepare orthographic and pictorial views;

(C) prepare auxiliary views;

(D) prepare section views;

(E) project points and construct lines to build geometric forms;

(F) construct true length of lines and true size of planes by the revolution method;

(G) draw developments using radial line, parallel line, and triangulation methods;

(H) construct piercing points and intersection of planes using edge-view and cutting plane methods;

(I) prepare and revise annotated multi-dimensional production drawings in computer-aided drafting and design to industry standards; and

(J) demonstrate knowledge of effective file structure and management.

(6) The student uses engineering design methodologies. The student is expected to:

(A) understand and discuss principles of ideation;

(B) think critically, identify the system constraints, and make fact-based decisions;

(C) use rational thinking to develop or improve a product;

(D) apply decision-making strategies when developing solutions;

(E) use an engineering notebook to record prototypes, corrections, and/or mistakes in the design process; and

(F) use an engineering notebook to record the final design, construction, and manipulation of finished projects.

(7) The student applies concepts of engineering to specific problems. The student is expected to:

(A) use a variety of technologies to design components;

(B) use tools, laboratory equipment, and precision measuring instruments to develop prototypes;

(C) research applications of different types of computer-aided drafting and design software; and

(D) use multiple software applications for concept presentations.

(8) The student designs products using appropriate design processes and techniques. The student is expected to:

(A) interpret engineering drawings;

(B) identify areas where quality, reliability, and safety can be designed into a product;

(C) improve a product design to meet a specified need;

(D) produce engineering drawings to industry standards; and

(E) describe potential patents and the patenting process.

(9) The student builds a prototype using the appropriate tools, materials, and techniques. The student is expected to:

(A) identify and describe the steps needed to produce a prototype;

(B) identify and use appropriate tools, equipment, machines, and materials to produce the prototype; and

(C) present the prototype using a variety of media.

Source: The provisions of this §130.365 adopted to be effective August 23, 2010, 34 TexReg 5941.

A2.4 Advanced Engineering Design and Presentation

§130.366. Advanced Engineering Design and Presentation (Two to Three Credits).

(a) General requirements. This course is recommended for students in Grades 11-12. Prerequisite: Engineering Design and Presentation.

(b) Introduction. This course will provide students the opportunity to master computer software applications in a variety of engineering and technical fields. This course further develops the process of engineering thought and application of the design process.

(c) Knowledge and skills.

(1) The student gains knowledge of and demonstrates the skills necessary for success in the workplace. The student is expected to:

(A) distinguish the differences between an engineering technician, engineering technologist, and engineer;

(B) identify employment and career opportunities;

(C) investigate and work toward industry certifications;

(D) demonstrate the principles of teamwork related to engineering and technology;

(E) identify and use appropriate work habits;

(F) demonstrate knowledge related to governmental regulations, including health and safety;

(G) discuss ethical issues related to engineering and technology and incorporate proper ethics in submitted projects;

(H) demonstrate respect for diversity in the workplace;

(I) demonstrate appropriate actions and identify consequences relating to discrimination, harassment, and equality;

(J) demonstrate effective oral and written communication skills using a variety of software applications and media; and

(K) explore career preparation learning experiences, including, but not limited to, job shadowing, mentoring, and apprenticeship training.

(2) The student participates in team projects in various roles. The student is expected to:

(A) understand and discuss how teams function;

(B) use teamwork to solve problems; and

(C) serve as a team leader and a team member and demonstrate appropriate attitudes while participating in team projects.

(3) The student develops skills for managing a project. The student is expected to:

(A) use time-management techniques to develop and maintain work schedules and meet deadlines;

(B) complete projects according to established criteria;

(C) participate in the organization and operation of a real or simulated engineering project; and

(D) develop a plan for production of an individual product.

(4) The student demonstrates principles of project documentation and work flow. The student is expected to:

(A) complete work orders and related documentation;

(B) identify factors affecting cost and strategies to minimize costs;

(C) prepare a project budget;

(D) prepare a production schedule;

(E) identify intellectual property and other legal restrictions; and

(F) read and interpret technical drawings, manuals, and bulletins.

(5) The student applies the concepts and skills of computer-aided drafting and design software to perform the following tasks. The student is expected to:

(A) prepare drawings to American National Standards Institute and International Standards Organization graphic standards;

(B) customize software user interface by creating blocks, attributes, and symbol libraries;

(C) prepare advanced sectional views and isometrics;

(D) draw detailed parts, assembly diagrams, and sub-assembly diagrams;

(E) indicate tolerances and standard fittings using appropriate library functions;

(F) prepare highway plan and profile drawings, including utility locations;

(G) prepare functional block diagrams for project management and decision making;

(H) prepare functional wiring harness diagrams;

(I) prepare electronic schematics to industry standards, including logic diagrams;

(J) prepare advanced development drawings; and

(K) identify the functions of computer hardware devices.

(6) The student practices safe and proper work habits. The student is expected to:

(A) master relevant safety tests;

(B) follow safety guidelines as described in various manuals, instructions, and regulations;

(C) identify and classify hazardous materials and wastes according to Occupational Safety and Health Administration regulations;

(D) dispose of hazardous materials and wastes appropriately;

(E) perform maintenance on selected tools, equipment, and machines;

(F) handle and store tools and materials correctly; and

(G) describe the results of negligent or improper maintenance.

(7) The student uses engineering design methodologies. The student is expected to:

(A) understand and discuss principles of system ideation;

(B) think critically, identify the system constraints, and make fact-based decisions;

(C) use rational thinking to develop or improve a system;

(D) apply decision-making strategies when developing solutions;

(E) identify quality-control issues in engineering design and production;

(F) describe perceptions of the quality of products and how they affect engineering decisions;

(G) use an engineering notebook to record prototypes, corrections, and/or mistakes in the design process; and

(H) use an engineering notebook to record the final design, construction, and manipulation of finished projects.

(8) The student applies concepts of engineering to specific problems. The student is expected to:

(A) use a variety of technologies to design systems;

(B) use tools, laboratory equipment, and precision measuring instruments to develop prototypes;

(C) research applications of different types of computer-aided drafting and design software; and

(D) use multiple software applications for concept presentations.

(9) The student designs systems using appropriate design processes and techniques. The student is expected to:

(A) interpret engineering drawings;

(B) identify areas where quality, reliability, and safety can be designed into a system;

(C) improve a system design to meet a specified need, including properties of materials selected;

(D) produce engineering drawings to industry standards; and

(E) describe potential patents and the patenting process.

(10) The student builds a prototype using the appropriate tools, materials, and techniques. The student is expected to:

(A) identify and describe the steps needed to produce a prototype;

(B) identify and use appropriate tools, equipment, machines, and materials to produce the prototype; and

(C) present the prototype using a variety of media.

Source: The provisions of this §130.366 adopted to be effective August 23, 2010, 34 TexReg 5941.

A2.5 Engineering Math

§130.367. Engineering Mathematics (One Credit).

(a) General requirements. This course is recommended for students in Grades 11-12. Prerequisite: Algebra II.

(b) Introduction. Engineering Mathematics is a course where students solve and model robotic design problems. Students use a variety of mathematical methods and models to represent and analyze problems involving data acquisition, spatial applications, electrical measurement, manufacturing processes, materials engineering, mechanical drives, pneumatics, process control systems, quality control, and robotics with computer programming.

(c) Knowledge and skills.

(1) The student uses mathematically based hydraulics concepts to measure and find pump output, understand pressure versus cylinder force, and understand flow rate verses cylinder speed. The student is expected to:

(A) explain how flow rate can be measured in gallons per minute and liters per minute;

(B) calculate and record data using actual flow rates from a flow meter chart;

(C) calculate, measure, and illustrate the force output and speed of an extending and retracting cylinder; and

(D) determine and depict the stroke time of a cylinder in gallons per minute.

(2) The student uses mathematical concepts of structure design to define and describe statics, acquire data, apply concepts of moments and bending stress, and apply concepts of truss design and analysis. The student is expected to:

(A) calculate a resultant force;

(B) apply the concept of equilibrium to force calculations;

(C) calculate a force using a free-body diagram;

(D) develop an application of strain gauges that determines mathematically and experimentally the force on a structural element;

(E) calculate the magnitude of force applied to a rotational system;

(F) apply the moment equilibrium equation to force calculations;

(G) calculate, measure, and illustrate a bending moment on a beam;

(H) determine and depict the bending stress in a beam;

(I) calculate forces in truss using a six-step problem-solving method;

(J) apply modulus of elasticity to the deflection of beams;

(K) calculate a beam deflection for a given load;

(L) determine and depict the critical load for buckling using Euler's formula; and

(M) design and apply factors of safety to column and beam design.

(3) The student understands the properties of trigonometry in spatial applications. The student is expected to:

(A) apply trigonometric ratios, including sine, cosine, and tangent, to spatial problems; and

(B) determine the distance and height of remote objects using trigonometry.

(4) The student understands the concepts of design processes with multi-view computer-aided drafting and design drawings for facilities layouts, precision part design, process design, computer-aided manufacturing for lathe, and injection mold design. The student is expected to:

(A) determine a dimension of an object given a scaled drawing having no dimensions;

(B) compare and contrast the function of production time and production rate;

(C) calculate, analyze, and apply the proper cycle time and machines required to meet a specified production rate;

(D) demonstrate the calculation and application of output shaft speed and torque in a gear train;

(E) create a method to determine the direction of a gear train's output shaft;

(F) design a spur gear train given speed and torque requirements;

(G) calculate and apply the proper spacing between the centers of gears in a gear train to a specified tolerance;

(H) apply positional tolerances to assembled parts;

(I) predict the production cost of a product given process information and a bill of materials;

(J) apply the correct spindle speed for a computer-aided manufacturing device by calculation;

(K) apply the correct feed rate for a computer-aided manufacturing device by using calculation;

(L) calculate the pressure drop in an injection mold system;

(M) design a gate size in an injection mold system using the gate width and depth formulas;

(N) determine the size of a mold; and

(O) create size runners for a multi-cavity mold.

(5) The student calculates electronic quantities and uses electrical measuring instruments to experimentally test their calculations. The student is expected to:

(A) apply common electronic formulas to solve problems;

(B) use engineering notation to properly describe calculated and measured values;

(C) compare and contrast the mathematical differences between a direct current and alternating current;

(D) show the effect of an inductor in an alternating current circuit and give an application;

(E) show the effect of a capacitor in an alternating current circuit and give an application;

(F) create a resistive capacitive timing circuit in a time-delay circuit;

(G) calculate the output voltage and current load of a transformer;

(H) calculate the effective alternating current voltage root mean square given the peak alternating current voltage and the peak alternating current voltage given the root mean square value; and

(I) calculate the cost of operating an electric motor.

(6) The student applies mathematical principles of pneumatic pressure and flow to explain pressure versus cylinder force, apply and manipulate pneumatic speed control circuits, and describe maintenance of pneumatic equipment, centrifugal pump operation and characteristics, data acquisition systems, pump power, and pump system design. The student is expected to:

(A) calculate the force output of a cylinder in retraction and extension;

(B) demonstrate how gage pressure and absolute pressure are different;

(C) consider and analyze Boyle's Law to explain its significance;

(D) convert air volumes at pressures to free air volumes;

(E) analyze dew point and relative humidity to explain their importance;

(F) explain the importance of the two units of pump flow rate measurement;

(G) convert between mass and volumetric flow rate;

(H) convert between units of head and pressure;

(I) explain the importance of total dynamic head in terms of suction and discharge head;

(J) demonstrate the measurement of the total head of a centrifugal pump;

(K) calculate friction head loss in a given pipe length using head loss tables and charts;

(L) calculate total suction lift, total suction head, total discharge head, and the total dynamic head of a system for a given flow rate;

(M) analyze and explain the importance of sensitivity in relation to pumps;

(N) use a data acquisition system to measure and mathematically analyze pressure drop characteristics in a pipe;

(O) analyze a flat plate orifice flow meter for operation and demonstrate an application;

(P) use a data acquisition system to measure and analyze mathematically data from a flat plate orifice flow meter;

(Q) calculate hydraulic power;

(R) explain the importance of brake horsepower and centrifugal pump efficiency;

(S) calculate centrifugal pump brake horsepower given pump efficiency and hydraulic power;

(T) calculate the effect of impeller diameter on the flow rate of a centrifugal pump and pump head;

(U) predict the effect of impeller diameter on a pump head capacity curve;

(V) calculate the effect of impeller speed on the flow rate of a centrifugal pump and pump head;

(W) calculate net positive suction head available and required result to explain its importance; and

(X) analyze the proper size of a centrifugal pump for a given application.

(7) The student applies mathematical principles of manufacturing processes in lathe operations and computer numerical control mill programming and calculates speeds and feeds for machining tools, including special cutting tools. The student is expected to:

(A) calculate the diameter of a tap drill given the thread specifications for a given application;

(B) analyze and set the point reference zero and the tool offsets in a computer numerical control mill;

(C) calculate spindle speeds for various machine tools; and

(D) calculate and select the proper feed rate for machine tool operations.

(8) The student applies mathematical principles of material engineering, including tensile strength analysis, data acquisition systems, compression testing and analysis, shear and hardness testing and analysis, and design evaluation. The student is expected to:

(A) calculate stress, strain, and elongation using the modulus of elasticity for a material or model with a given set of data;

(B) analyze and explain the importance of sensitivity in relation to material engineering;

(C) analyze the operation of a data acquisition formula;

(D) mathematically analyze a part for stress and strain under a compression load;

(E) calculate shear stress for a material with a given set of data;

(F) use the Brinell hardness number to determine the ultimate tensile strength of a material;

(G) design and apply factors of safety to material engineering; and

(H) create material testing conditions for a model using equipment such as a polariscope.

(9) The student applies mathematical principles for mechanical drives, including levers, linkages, cams, turnbuckles, pulley systems, gear drives, key fasteners, v-belt drives, and chain drives. The student is expected to:

(A) calculate the weight of an object for a given mass;

(B) analyze and calculate torque for a given application using the proper units of measurement;

(C) calculate the magnitude of force applied to a rotational system;

(D) calculate the mechanical advantage of first-, second-, and third-class levers;

(E) compare and contrast the advantages and disadvantages of the three classes of levers for different applications;

(F) calculate and analyze the coefficient of friction in its proper units of measurement;

(G) analyze and calculate mechanical advantage for simple machines using proper units of measurement;

(H) calculate the mechanical advantage of gear drive systems;

(I) compare and contrast at least two methods of loading a mechanical drive system;

(J) calculate rotary mechanical power applied to an application;

(K) analyze the mechanical efficiency of a given application;

(L) demonstrate various examples of pitch and analyze its proper application;

(M) calculate the shaft speed and torque of a belt drive and chain drive system; and

(N) calculate sprocket ratio and analyze importance to various applications.

(10) The student applies mathematical principles of quality assurance, including using precision measurement tools, statistical process control, control chart operation, analysis of quality assurance control charts, geometric dimensioning

and tolerancing, and location, orientation, and form tolerances. The student is expected to:

(A) evaluate the readings of dial calipers and micrometers to make precise measurements;

(B) use at least three measures of central tendency to analyze the quality of a product;

(C) use a manually constructed histogram to analyze a given a set of data;

(D) construct and use a mean value and range chart to determine if a process remains constant over a specified range of time;

(E) examine the maximum and minimum limits of a dimension given its tolerance; and

(F) use position tolerance to calculate the location of a hole.

(11) The student applies mathematical principles of robotics and computer programming of robotic mechanisms in point-to-point assembly, calculating working envelope and computer system conversions. The student is expected to:

(A) create a pallet load configuration and program a robot to execute the operation;

(B) calculate the working envelope of a robotic arm; and

(C) convert between the hexadecimal, binary, and decimal number systems.

Source: The provisions of this §130.367 adopted to be effective August 23, 2010, 34 TexReg 5941.

A2.6 Robotics and Automation

§130.370. Robotics and Automation (One to Two Credits).

(a) General requirements. This course is recommended for students in Grades 11-12. Recommended prerequisites: Concepts of Engineering and Technology and Electronics.

(b) Introduction. Students enrolled in this course will demonstrate knowledge and skills necessary for the robotic and automation industry. Through implementation of the design process, students will transfer advanced academic skills to component designs in a project-based environment. Students will build prototypes or use simulation software to test their designs. Additionally, students explore career opportunities, employer expectations, and educational needs in the robotic and automation industry.

(c) Knowledge and skills.

(1) The student demonstrates the skills necessary for success in the workplace. The student is expected to:

(A) distinguish the differences between an engineering technician, engineering technologist, and engineer;

(B) identify employment and career opportunities;

(C) investigate and work toward industry certifications;

(D) demonstrate the principles of teamwork related to engineering and technology;

(E) identify and use appropriate work habits;

(F) demonstrate knowledge related to governmental regulations, including health and safety;

(G) discuss ethical issues related to engineering and technology and incorporate proper ethics in submitted projects;

(H) demonstrate respect for diversity in the workplace;

(I) demonstrate appropriate actions and identify consequences relating to discrimination, harassment, and equality;

(J) demonstrate effective oral and written communication skills using a variety of software applications and media; and

(K) explore career preparation learning experiences, including, but not limited to, job shadowing, mentoring, and apprenticeship training.

(2) The student participates in team projects in various roles. The student is expected to:

(A) understand and discuss how teams function;

(B) use teamwork to solve problems; and

(C) serve as a team leader and a team member and demonstrate appropriate attitudes while serving in those roles.

(3) The student develops skills for managing a project. The student is expected to:

(A) use time-management techniques to develop and maintain work schedules and meet deadlines;

(B) complete work according to established criteria;

(C) participate in the organization and operation of a real or simulated engineering project; and

(D) develop a plan for production of an individual product.

(4) The student practices safe and proper work habits. The student is expected to:

(A) master relevant safety tests;

(B) follow safety guidelines as described in various manuals, instructions, and regulations;

(C) identify and classify hazardous materials and wastes according to Occupational Safety and Health Administration regulations;

(D) dispose of hazardous materials and wastes appropriately;

(E) perform maintenance on selected tools, equipment, and machines;

(F) handle and store tools and materials correctly; and

(G) describe the results of negligent or improper maintenance.

(5) The student develops the ability to use and maintain technological products, processes, and systems. The student is expected to:

(A) demonstrate the use of computers to manipulate a robotic or automated system and associated subsystems;

(B) troubleshoot and maintain systems and subsystems to ensure safe and proper function and precision operation;

(C) demonstrate knowledge of process control factors; and

(D) demonstrate knowledge of motors, gears, and gear trains used in the robotic or automated systems.

(6) The student develops an understanding of the advanced concepts of physics, robotics, and automation. The student is expected to:

(A) demonstrate knowledge of rotational dynamics, weight, friction, and traction factors required for the operation of robotic and automated systems;

(B) demonstrate knowledge of torque and power factors used in the operation of robotic systems;

(C) demonstrate knowledge of feedback control loops to provide information; and

(D) demonstrate knowledge of different types of sensors used in robotic or automated systems and their operations.

(7) The student develops an understanding of the characteristics and scope of manipulators and end effectors required for a robotic or automated system to function. The student is expected to:

(A) demonstrate knowledge of robotic or automated system arm construction;

(B) understand and discuss the relationship of torque, gear ratio, and weight of payload in a robotic or automated system operation; and

(C) demonstrate knowledge of end effectors and their use in linkages and the gearing of a robotic or automated system.

(8) The student uses engineering design methodologies. The student is expected to:

(A) understand and discuss principles of ideation;

(B) think critically, identify the system constraints, and make fact-based decisions;

(C) use rational thinking to develop or improve a product;

(D) apply decision-making strategies when developing solutions;

(E) identify quality-control issues in engineering design and production;

(F) describe perceptions of the quality of products and how they affect engineering decisions;

(G) use an engineering notebook to record prototypes, corrections, and or mistakes in the design process; and

(H) use an engineering notebook to record the final design, construction, and manipulation of finished projects.

(9) The student learns the function and application of the tools, equipment, and materials used in robotic and automated systems through specific project-based assessments. The student is expected to:

(A) safely use tools and laboratory equipment to construct and repair systems;

(B) use precision measuring instruments to analyze systems and prototypes; and

(C) use multiple software applications to simulate robot behavior and present concepts.

(10) The student designs products using appropriate design processes and techniques. The student is expected to:

(A) interpret industry standard system schematics;

(B) identify areas where quality, reliability, and safety can be designed into a product;

(C) improve a product design to meet a specified need;

(D) understand use of sensors in a robotic or automated system;

(E) produce system schematics to industry standards;

(F) evaluate design solutions using conceptual, physical, and mathematical models at various times during the design process to check for proper functionality and to note areas where improvements are needed;

(G) implement a system to identify and track all components of the robotic or automated system and all elements involved with the operation, construction, and manipulative functions; and

(H) describe potential patents and the patenting process.

(11) The student builds a prototype using the appropriate tools, materials, and techniques. The student is expected to:

(A) identify and describe the steps needed to produce a prototype;

(B) identify and use appropriate tools, equipment, machines, and materials to produce the prototype;

(C) implement sensors in a robotic or automated system;

(D) construct a robotic or automated system to perform specified operations using the design process;

(E) test and evaluate the design in relation to pre-established requirements such as criteria and constraints and refine as needed;

(F) refine the design of a robotic or automated system to ensure quality, efficiency, and manufacturability of the final product; and

(G) present the prototype using a variety of media.

Source: The provisions of this §130.370 adopted to be effective August 23, 2010, 34 TexReg 5941.

A2.7 Scientific Research and Design

§130.372. Scientific Research and Design (One Science Credit).

(a) General requirements. This course is recommended for students in Grades 11-12. Prerequisite: one unit of high school science. To receive credit in science, students must meet the 40% laboratory and fieldwork requirement identified in §74.3(b)(2)(C) of this title (relating to Description of a Required Secondary Curriculum).

(b) Introduction.

(1) Nature of science. Science, as defined by the National Academy of Sciences, is the "use of evidence to construct testable explanations and predictions of natural phenomena, as well as the knowledge generated through this process." This vast body of changing and increasing knowledge is described by physical, mathematical, and conceptual models. Students should know that some questions are outside the realm of science because they deal with phenomena that are not scientifically testable.

(2) Scientific inquiry. Scientific inquiry is the planned and deliberate investigation of the natural world. Scientific methods of investigation are experimental, descriptive, or comparative. The method chosen should be appropriate to the question being asked.

(3) Science and social ethics. Scientific decision making is a way of answering questions about the natural world. Students should be able to distinguish between scientific decision-making methods (scientific methods) and ethical and social decisions that involve science (the application of scientific information).

(4) Scientific systems. A system is a collection of cycles, structures, and processes that interact. All systems have basic properties that can be described in space, time, energy, and matter. Change and constancy occur in systems as patterns and can be observed, measured, and modeled. These patterns help to make predictions that can be scientifically tested. Students should analyze a system in terms of its components and how these components relate to each other, to the whole, and to the external environment.

(c) Knowledge and skills.

(1) The student, for at least 40% of instructional time, conducts laboratory and field investigations using safe, environmentally appropriate, and ethical practices. These investigations must involve actively obtaining and analyzing data with physical equipment, but may also involve experimentation in a simulated environment as well as field observations that extend beyond the classroom. The student is expected to:

(A) demonstrate safe practices during laboratory and field investigations; and

(B) demonstrate an understanding of the use and conservation of resources and the proper disposal or recycling of materials.

(2) The student uses a systematic approach to answer scientific laboratory and field investigative questions. The student is expected to:

(A) know the definition of science and understand that it has limitations, as specified in subsection (b)(1) of this section;

(B) know that scientific hypotheses are tentative and testable statements that must be capable of being supported or not supported by observational evidence. Hypotheses of durable explanatory power which have been tested over a wide variety of conditions are incorporated into theories;

(C) know that scientific theories are based on natural and physical phenomena and are capable of being tested by multiple independent researchers. Unlike hypotheses, scientific theories are well-established and highly-reliable explanations, but may be subject to change as new areas of science and new technologies are developed;

(D) distinguish between scientific hypotheses and scientific theories;

(E) design and implement investigative procedures, including making observations, asking well-defined questions, formulating testable hypotheses, identifying variables, selecting appropriate equipment and technology, and evaluating numerical answers for reasonableness;

(F) collect and organize qualitative and quantitative data and make measurements with accuracy and precision using tools such as calculators, spreadsheet software, data-collecting probes, computers, standard laboratory glassware, microscopes, various prepared slides, stereoscopes, metric rulers, electronic balances, gel electrophoresis apparatuses, micropipettors, hand lenses, Celsius thermometers, hot plates, lab notebooks or journals, timing devices, cameras, and meter sticks;

(G) analyze, evaluate, make inferences, and predict trends from data;

(H) identify and quantify causes and effects of uncertainties in measured data;

(I) organize and evaluate data and make inferences from data, including the use of tables, charts, and graphs; and

(J) communicate valid conclusions supported by the data through various methods such as lab reports, labeled drawings, graphic organizers, journals, summaries, oral reports, and technology-based reports.

(3) The student uses critical thinking, scientific reasoning, and problem solving to make informed decisions within and outside the classroom. The student is expected to:

(A) in all fields of science, analyze, evaluate, and critique scientific explanations by using empirical evidence, logical reasoning, and experimental and observational testing, including examining all sides of scientific evidence of those scientific explanations, so as to encourage critical thinking by the student;

(B) communicate and apply scientific information extracted from various sources such as current events, news reports, published journal articles, and marketing materials;

(C) draw inferences based on data related to promotional materials for products and services;

(D) explain the impacts of the scientific contributions of a variety of historical and contemporary scientists on scientific thought and society;

(E) research and describe the connections between science and future careers; and

(F) express and interpret relationships symbolically in accordance with accepted theories to make predictions and solve problems mathematically, including problems requiring proportional reasoning and graphical vector addition.

(4) The student formulates hypotheses to guide experimentation and data collection. The student is expected to:

(A) perform background research with respect to an investigative problem; and

(B) examine hypotheses generated to guide a research process by evaluating the merits and feasibility of the hypotheses.

(5) The student analyzes published research. The student is expected to:

(A) identify the scientific methodology used by a researcher;

(B) examine a prescribed research design and identify dependent and independent variables;

(C) evaluate a prescribed research design to determine the purpose for each of the procedures performed; and

(D) compare the relationship of the hypothesis to the conclusion.

(6) The student develops and implements investigative designs. The student is expected to:

(A) interact and collaborate with scientific researchers and/or other members of the scientific community to complete a research project;

(B) identify and manipulate relevant variables within research situations;

(C) use a control in an experimental process; and

(D) design procedures to test hypotheses.

(7) The student collects, organizes, and evaluates qualitative and quantitative data obtained through experimentation. The student is expected to:

(A) record observations and events as they occur within an investigation;

(B) acquire, manipulate, and analyze data using equipment and technology;

(C) construct data tables to organize information collected in an experiment; and

(D) evaluate data using statistical methods to recognize patterns, trends, and proportional relationships.

(8) The student knows how to synthesize valid conclusions from qualitative and quantitative data. The student is expected to:

(A) synthesize conclusions supported by research data;

(B) consider and communicate alternative explanations for observations and results; and

(C) identify limitations within the research process and provide recommendations for additional research.

(9) The student communicates conclusions clearly and concisely to an audience of professionals. The student is expected to:

(A) construct charts, tables, and graphs in facilitating data analysis and in communicating experimental results clearly and effectively using technology; and

(B) suggest alternative explanations from observations or trends evident within the data or from prompts provided by a review panel.

Source: The provisions of this §130.372 adopted to be effective August 23, 2010, 34 TexReg 5941.

A2.8 Engineering Design and Problem Solving

§130.373. Engineering Design and Problem Solving (One Science Credit).

(a) General requirements. This course is recommended for students in Grades 11-12. Prerequisites: Geometry, Algebra II, Chemistry, and Physics.

(b) Introduction.

(1) Engineering design is the creative process of solving problems by identifying needs and then devising solutions. This solution may be a product, technique, structure, process, or many other things depending on the problem. Science aims to understand the natural world, while engineering seeks to shape this world to meet human needs and wants. Engineering design takes into consideration limiting factors or "design under constraint." Various engineering disciplines address a broad spectrum of design problems using specific concepts from the sciences and mathematics to derive a solution. The design process and problem solving are inherent to all engineering disciplines.

(2) Engineering Design and Problem Solving reinforces and integrates skills learned in previous mathematics and science courses. This course emphasizes solving problems, moving from well defined toward more open ended, with real-world application. Students apply critical-thinking skills to justify a solution from multiple design options. Additionally, the course promotes interest in and understanding of career opportunities in engineering.

(3) This course is intended to stimulate students' ingenuity, intellectual talents, and practical skills in devising solutions to engineering design problems. Students use the engineering design process cycle to investigate, design, plan, create, and evaluate solutions. At the same time, this course fosters awareness of the social and ethical implications of technological development.

(c) Knowledge and skills.

(1) The student, for at least 40% of instructional time, conducts engineering field and laboratory activities using safe, environmentally appropriate, and ethical practices. The student is expected to:

(A) demonstrate safe practices during engineering field and laboratory activities; and

(B) make informed choices in the use and conservation of resources, recycling of materials, and the safe and legal disposal of materials.

(2) The student applies knowledge of science and mathematics and the tools of technology to solve engineering design problems. The student is expected to:

(A) apply scientific processes and concepts outlined in the Texas Essential Knowledge and Skills (TEKS) for Biology, Chemistry, or Physics relevant to engineering design problems;

(B) apply concepts, procedures, and functions outlined in the TEKS for Algebra I, Geometry, and Algebra II relevant to engineering design problems;

(C) select appropriate mathematical models to develop solutions to engineering design problems;

(D) integrate advanced mathematics and science skills as necessary to develop solutions to engineering design problems;

(E) judge the reasonableness of mathematical models and solutions;

(F) investigate and apply relevant chemical, mechanical, biological, electrical, and physical properties of materials to engineering design problems;

(G) identify the inputs, processes, outputs, control, and feedback associated with open and closed systems;

(H) describe the difference between open-loop and closed-loop control systems;

(I) make measurements and specify tolerances with minimum necessary accuracy and precision;

(J) use appropriate measurement systems, including customary and International System (SI) of units; and

(K) use conversions between measurement systems to solve real-world problems.

(3) The student communicates through written documents, presentations, and graphic representations using the tools and techniques of professional engineers. The student is expected to:

(A) communicate visually by sketching and creating technical drawings using established engineering graphic tools, techniques, and standards;

(B) read and comprehend technical documents, including specifications and procedures;

(C) prepare written documents such as memorandums, emails, design proposals, procedural directions, letters, and technical reports using the formatting and terminology conventions of technical documentation;

(D) organize information for visual display and analysis using appropriate formats for various audiences, including, but not limited to, graphs and tables;

(E) evaluate the quality and relevance of sources and cite appropriately; and

(F) defend a design solution in a presentation.

(4) The student recognizes the history, development, and practices of the engineering professions. The student is expected to:

(A) identify and describe career options, working conditions, earnings, and educational requirements of various engineering disciplines such as those listed by the Texas Board of Professional Engineers;

(B) recognize that engineers are guided by established codes emphasizing high ethical standards;

(C) explore the differences, similarities, and interactions among engineers, scientists, and mathematicians;

(D) describe how technology has evolved in the field of engineering and consider how it will continue to be a useful tool in solving engineering problems;

(E) discuss the history and importance of engineering innovation on the United States economy and quality of life; and

(F) describe the importance of patents and the protection of intellectual property rights.

(5) The student creates justifiable solutions to open-ended problems using engineering design practices and processes. The student is expected to:

(A) identify and define an engineering problem;

(B) formulate goals, objectives, and requirements to solve an engineering problem;

(C) determine the design parameters associated with an engineering problem such as materials, personnel, resources, funding, manufacturability, feasibility, and time;

(D) establish and evaluate constraints pertaining to a problem, including, but not limited to, health, safety, social, environmental, ethical, political, regulatory, and legal;

(E) identify or create alternative solutions to a problem using a variety of techniques such as brainstorming, reverse engineering, and researching engineered and natural solutions;

(F) test and evaluate proposed solutions using methods such as models, prototypes, mock-ups, simulations, critical design review, statistical analysis, or experiments;

(G) apply structured techniques to select and justify a preferred solution to a problem such as a decision tree, design matrix, or cost-benefit analysis;

(H) predict performance, failure modes, and reliability of a design solution; and

(I) prepare a project report that clearly documents the designs, decisions, and activities during each phase of the engineering design process.

(6) The student manages an engineering design project. The student is expected to:

(A) participate in the design and implementation of a real or simulated engineering project;

(B) develop a plan and timeline for completion of a project;

(C) work in teams and share responsibilities, acknowledging, encouraging, and valuing contributions of all team members;

(D) compare and contrast the roles of a team leader and other team responsibilities;

(E) identify and manage the resources needed to complete a project;

(F) use a budget to determine effective strategies to meet cost constraints;

(G) create a risk assessment for an engineering design project;

(H) analyze and critique the results of an engineering design project; and

(I) maintain an engineering notebook that chronicles work such as ideas, concepts, inventions, sketches, and experiments.

Source: The provisions of this §130.373 adopted to be effective August 23, 2010, 34 TexReg 5941.

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