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The engineering design process as a model for STEM curriculum design

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THE ENGINEERING DESIGN PROCESS

AS A MODEL FOR STEM

CURRICULUM DESIGN

by

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ABSTRACT

Engaging pedagogies have been proven to be effective in the promotion of deep learning for science, technology, engineering, and mathematics (STEM) students. In many cases, academic institutions have shown a desire to improve education by implementing more engaging techniques in the classroom. The research framework established in this dissertation has been governed by the axiom that students should obtain a deep understanding of fundamental topics while being motivated to learn through engaging techniques. This research lays a foundation for future analysis and modeling of the curriculum design process where specific educational research questions can be considered using standard techniques. Further, a clear curriculum design process is a key step towards establishing an axiomatic approach for engineering education. A danger is that poor implementation of engaging techniques will counteract the intended effects. Poor implementation might provide students with a "fun" project, but not the desired deep understanding of the fundamental STEM content.

Knowing that proper implementation is essential, this dissertation establishes a model for STEM curriculum design, based on the well-established engineering design process. Using this process as a perspective to model curriculum design allows for a structured approach. Thus, the framework for STEM curriculum design, established here, provides a guided approach for seamless integration of fundamental topics and engaging pedagogies. The main steps, or phases, in engineering design are: Problem Formulation, Solution Generation, Solution Analysis, and Solution Implementation. Layering engineering design with education curriculum theory, this dissertation establishes a clear framework for curriculum design. Through ethnographic engagement by this researcher, several overarching themes are revealed through the creation of curricula using the design process.

The application of the framework to specific curricula was part of this dissertation research. Examples of other STEM curricula using the framework were also presented. Moreover, the framework is presented in such a way that it can be implemented by other educational design teams.

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DEDICATION

To my parents…my father, Dan Corbett, an engineer and my mother, Vicki Corbett, an educator; without your influences I would never have found such a unique combination between engineering and education that I enjoy so much.

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CHAPTER 1

INTRODUCTION

1.1 STEM Education

Science, Technology, Engineering, and Mathematics (STEM) educators, for years, have been trying to improve the education process for STEM students [1-4]. One goal of the educator is to create a classroom environment that is more engaging and promotes transfer in the students' learning. Successful transfer [5] is shown by students not only learning a concept in an isolated instance but rather being able to transfer what is learned to other applications. The National Research Council [5] for psychology has identified some essential concepts for both the teacher and learner in order to encourage deep understanding and the ability to transfer knowledge. Concepts identified by the National Research Council [5] are (a) learning the fundamentals is key, (b) too much context could be harmful and instead some abstraction could promote better transfer, (c) maintaining a level of excitement and engagement leads to deeper understanding, and (d) course development should be based on the concept that new concepts builds on previous concepts. STEM educators strive to create environments that promote learning on a deep level. Engineering education literature [6, 7, 8] addresses the concepts identified by the National Research Council as their underlying themes. Because courses in an engineering curriculum build on one another, Engineering educators understand the need for students to transfer their knowledge of concepts from one class to another.

"Multiple Perspectives on Engaging Future Engineers," [6] is composed of many short essays written by a variety of experts in the fields of engineering, education, and psychology and discusses how to create an engaging environment for STEM students. Emphasis is placed on the necessity of creating connections with fundamental concepts to various applications. Adams, et al. [6] highlights five key ways to create connections that promote engagement. The first is to create a connection between "the new and the old." The second connection promotes engagement between the "abstract and concrete." Many times students new to a topic will have difficulty understanding the abstract. However, when the learner can relate to the problem the concepts are understood better. Instructors must keep in mind what the National Research Council [5] identifies: too much context could be harmful and instead, some abstraction could promote better transfer. A balance between the abstract and concrete is necessary. The instructor could present a topic using the more relatable example, but gradually move into the abstract so that students do not relate that concept to just one concrete example. The third connection needed for success in engaging students is "understanding and applying." The instructor needs to create an atmosphere where the students can apply the concepts they learn to an application. It is important that students relate to the application so that an engaging atmosphere is promoted. The fourth connection to engaging students is to "strive for structural connections, not just surface similarities." Many educators try to employ a simple "fun" task that engages students on a surface level but does not promote deep understanding with which students need to transfer. The final connection for engaging is to "be a model of the engineer that you expect your students to be." When an instructor is excited about learning and exhibits interest in the topics, then the students are more likely to follow suit. Techniques promoting engaging environments are found in many STEM classes where pedagogies are geared towards project-based instruction, inquiry-driven, and student-centered learning. According to Heller, Beil, Dam, and Hearum [7] the promotion of engagement and how it is found in the classroom is shown through pedagogical approaches, students working with their peers, activities, interaction with faculty, students having a positive perspective of the subject, and an environment that encourages feedback/discussions from students.

Engineering educators want to help students develop into expert engineers. Litzinger, Lattuca, Hadgraft, and Newstetter [8], learning science researchers and engineering educators, collaboratively discuss the goal of minimizing the time required for students to become experts in their fields. People do not develop into experts overnight or after only a few classes. Development of expertise occurs over many hours and many different experiences. The generally accepted rate to become an expert in a field is 10 years [8]. After 10 years, the expert can easily access his/her vast knowledge on topics in their given field. Expertise is shown in the ability of someone to create an organized structure of thought with their knowledge such that the information is easily accessible given various contexts. Basically someone who only has a surface level of understanding could not develop such a structure; thus, deep learning and transfer is necessary to achieve expertise status [8]. Minimizing the time required to become an expert in engineering can be fostered through the pedagogical approach of the instructor. Litzinger, et al. [8] emphasize the need to provide students with a learning environment that fosters deep understanding where the student can put into practice skills and techniques typically taught in the theoretical sense.

Many universities have pushed for courses with more project-based curricula; however, simply adding in a few projects does not achieve the goal of deep learning. If projects are presented on a surface level, students will not reap the potential benefits of a projects-based course. In order to develop the expertise [8] needed of engineers, not only exposure to, but involvement in, a variety of experiences throughout the course of curricular instruction is necessary.

Instructors must develop coursework that promotes deep learning by organizing courses around key concepts and fundamentals. Traditional methods of instruction often fail to provide the level of conceptual learning and analytical skills needed by students to foster expertise status, but methods that provide motivation and engagement have been shown to promote learning and in turn better develop expertise. Some of the methods discussed by Litzinger, et al. [8] identify this sort of instruction as peer tutoring/instruction, rigorous multistep problems containing applicable context, and authentic open-ended problems. An understanding of technical aspects of engineering is important for expertise, however, to minimize the time it takes for a student to develop into an expert, students must also be exposed to professionalism skills, communication skills, and teamwork skills [8]. Thus instructors should also incorporate opportunities for students to cultivate these skills in addition to the technical skills.

1.2 STEM Curricula

STEM educators must take action to put engaging techniques into practice in the STEM learning environment. In many universities across the nation, a fresh approach to STEM education has been taken with the promotion of project-based, intuition-driven courses, many of which are introduced in freshman level courses. These courses [9-11] display many of the key concepts established by the literature that promotes deep learning. Instructors have taken current content and supplemented the curriculum with projects that illustrate the fundamentals. Some curricula are completely redesigned to have engaging techniques, but in other cases projects are added as an afterthought. Simply adding a project to aid in discussion of a concept has its merits; however, poor implementation will detract from the fundamental concept being taught. Additionally, some of the projects or engaging techniques are implemented, but only reach a surface level of understanding for the students and, in turn, deep learning of the fundamental concept is not achieved. Figure 1-2 depicts a board analogously representing a curriculum containing the fundamental concepts with holes A, B, C, and D, where active learning components can be inserted. Figure 1-2 analogously relates the board in Figure 1-1 to the positive and negative methods of implementing active learning components in STEM curricula. The wooden board represents the fundamental topics, where each hole is a location for an active learning component. Part A in Figure 1-2 illustrates an active learning component that does not fully fit into the fundamental topic. Little contact is made with the fundamental topic, and as a whole there is poor correlation with the fundamentals. This is an example of inserting active learning components for the sole purpose of having active learning components. Part B depicts an active learning component that provides only a surface level of understanding to the fundamental topics. The active learning component is the same "shape" needed for understanding the fundamental topics; however, it is too small and will yield a disconnect between the fundamental topics and the active learning component. Typically when this happens, it is a "fun" project that students enjoy, but makes no substantial connection with the fundamentals. Part C illustrates the implementation of a significant active learning component. This project overshadows the fundamentals and in turn will not drive the fundamental concepts appropriately. Typically when this occurs, students are overwhelmed by the activity and ignore the fundamental topic. Finally, Part D depicts a seamless integration of the active learning component with the fundamental topics. It is a perfect fit making contact in the right places. Thus, students gain a deep understanding of the fundamental topics which they associate with the active learning component.

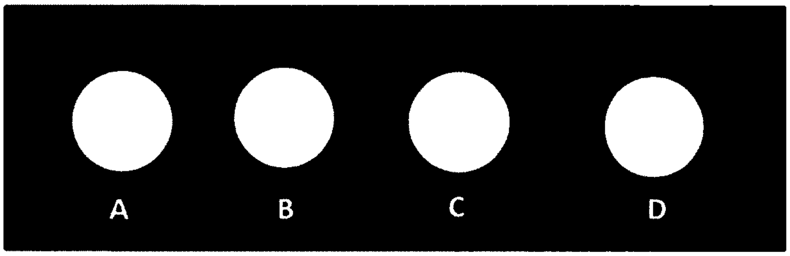

Figure 1-1: A board analogously representing a curriculum containing the fundamental concepts with holes where active learning components can be inserted

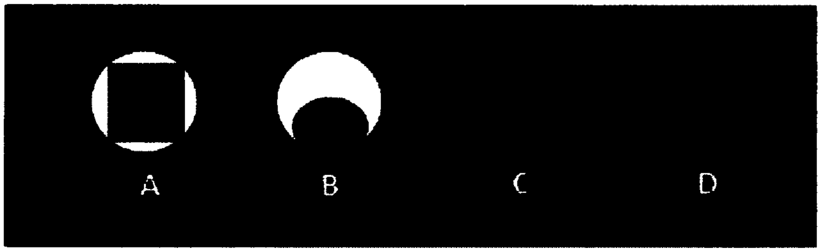

Figure 1-2: A board analogously representing STEM curriculum with the positive and negative methods of implementing active learning components.

An example of a popular project used in many STEM courses such as physics, mathematics, dynamics, etc., is a catapult. This project provides context for many fundamentals associated with projectile motion, trigonometry, velocity, acceleration and other physics fundamental topics. In most cases, students will most likely build the catapult, watch it shoot a projectile, and perhaps figure out where it would land given an initial velocity provided by the instructor. This approach to the catapult project has its merits; however, it only provides a surface level understanding of the fundamental concepts. Students do not acquire a deep understanding of the physics behind the catapult because, aside from building the structure, they simply watch an object being shot from the catapult. In the *LaTechSTEP* [12] program at Louisiana Tech University, the students not only have to build the catapult, they have to determine, using fundamental energy balance concepts, the initial velocity of the projectiles and calculate with minimal error the location where it will land. This promotes a level of inquiry and forces students to make connections and develop theories on how to find this initial velocity themselves. This program exhibits the level of instruction needed in STEM curricula. It provides students with the tools to learn for transfer. Simply using the "show and go" approach provides little long lasting benefits to the students [13].

As discussed above, simply plugging in a project whenever it seems appropriate does provide benefits to the students. However, if a course is examined as a whole and redesigned, a more seamless integration of fundamental concepts with projects can be achieved. The question is, however, can one achieve a complete overhaul of a particular curriculum while maintaining the integrity of the content? This dissertation will create a framework for STEM curriculum design; such that a seamless integration of fundamental topics and engaging pedagogies are implemented using the well established engineering design process. This dissertation provides examples of STEM curricula that utilized such a framework.

CHAPTER 2

BACKGROUND

2.1 Engineering Design Process

The Accreditation Board for Engineering and Technology (ABET) [14] is the accreditation body for college programs in the areas of engineering, technology, and computer science. For the past 80 years, ABET has been awarding accreditation for various technology-based education programs. Within the standards for accreditation of engineering programs, ABET has identified a key element in engineering education to be the understanding of the engineering design process. ABET defines engineering design [15] as "the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics, and the engineering sciences are applied to convert resources optimally to meet these stated needs."

Depending on the institution, engineering students are introduced to the engineering design process at varying levels of instruction. Those institutions with first-year engineering programs will typically introduce a version of the design process to the students in the first year with a freshman design experience [9-11, 16]. In some cases, institutions will integrate the design process within courses taught during the sophomore [17] and junior level curriculum [18-19]. Regardless of when the engineering design process is introduced, institutions following ABET accreditation standards have a culminating design experience for senior level engineers [15] aptly entitled Capstone Design [20-22]. During the senior capstone process, engineering students utilize the engineering design process to design, fabricate, and test a working prototype for a design scenario. The actual design process employed by the students in these courses varies slightly, dependent upon the text used in the specific course. Figure 2-1, Figure 2-2, and Figure 2-3 below are illustrations of the engineering design process as seen in different engineering design textbooks [23-25].

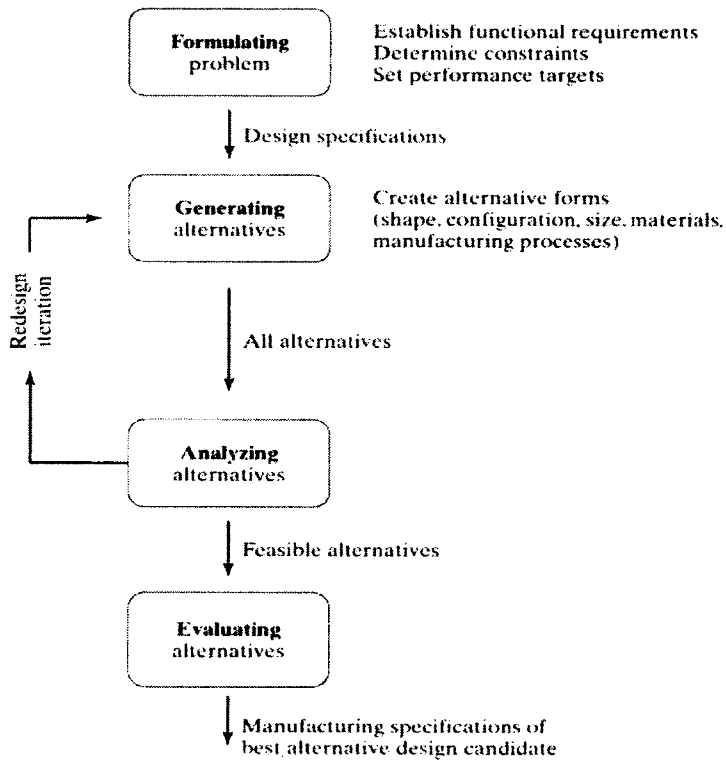

Figure 2-1: Illustration depicting the engineering design process as seen in the textbook *Engineering Design* [23].

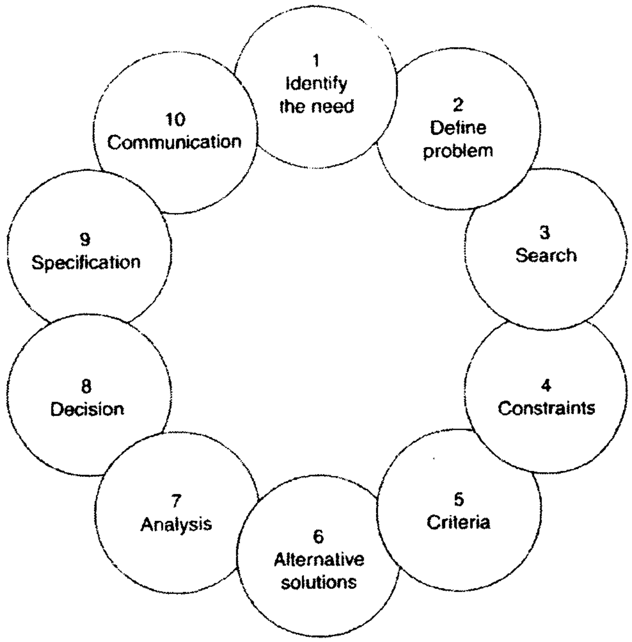

Figure 2-2: Illustration depicting the engineering design process as seen in the textbook *Engineering Fundamentals and Problem Solving* [24].

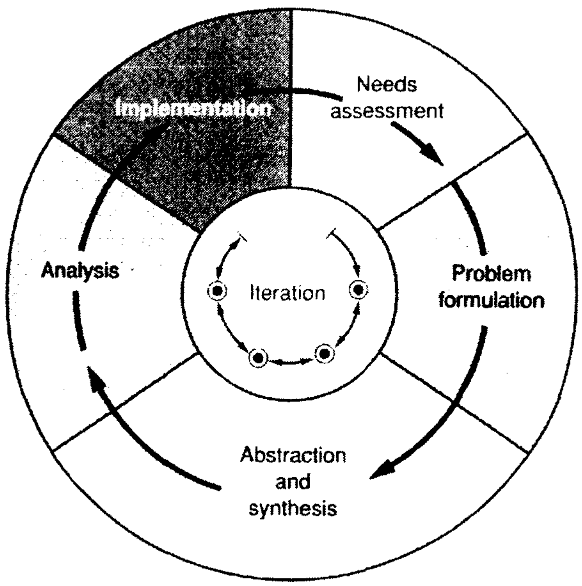

Figure 2-3: Illustration depicting the engineering design process as seen in the textbook *Engineering by Design* [25].

The steps depicted in the figures above vary slightly, but all illustrate the same themes of the design process. They all have some phase of a Problem Formulation, Solution Generation, Solution Analysis, and Solution Implementation. Within each of these four main phases, the various additional steps or sub-steps of the process are found. Additionally, engineering design textbooks [23-25] emphasize the iterative nature of the process. Iteration is the key to refining and optimizing the design. Figure 2-4 depicts the generalization of the steps in the engineering design process as well as its iterative natures.

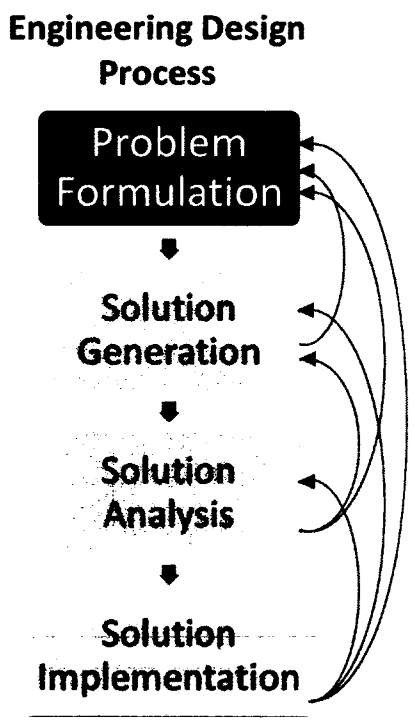

Figure 2-4: Illustration depicting a summarized version of the engineering design process.

The Problem Formulation phase is arguably the most critical stage in the engineering design process. To begin the design process, the design team must fully understand the scope of the problem to develop the optimum solution. This is achieved by clearly defining all parameters and aspects of the problem through discussion with experts and previously conducted research; thus, adequate time should be allotted to the definition of the problem statement. A clearly composed statement is needed in order develop a solution, and all aspects should be considered. A designer must understand the desired outcome as well as look at the various parameters that might influence the end result such as: time, space, funding, materials available, etc. Keeping these parameters in mind will help in narrowing down the core of the problem statement. Figure 2-5 [23] shows a flowchart of necessary aspects that should be addressed in order to fully formulate the problem statement.

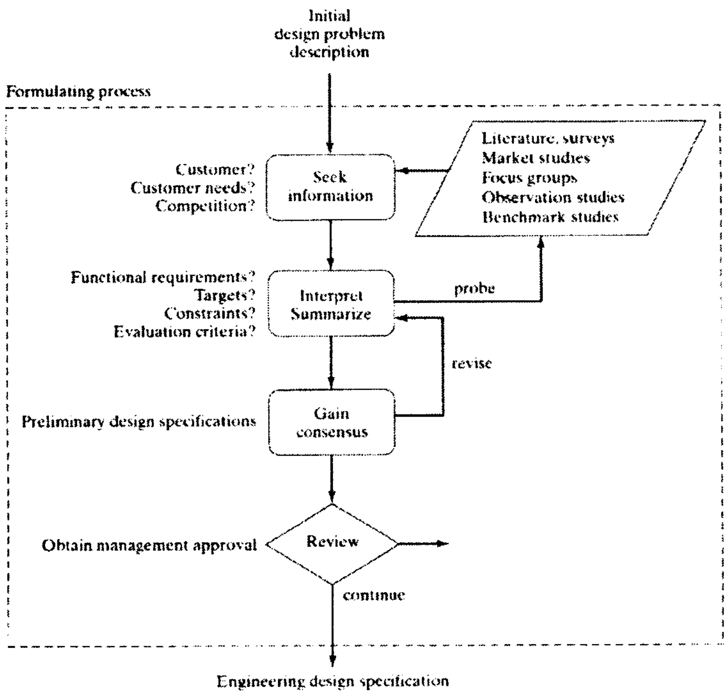

Figure 2-5: A flowchart identifying the formulation phase of the engineering design process [23].

In the Solution Generation phase the design team develops potential solutions to the problem statement. One of the most popular methods used in today's engineering design is brainstorming. An individual or team generates a list of possible solutions that could yield success in solving the problem. The list should be all-inclusive having no restriction on what is proposed. Allowing for creativity in solution generation can potentially spark solutions that may have been limited with restrictions on creativity. Many times the more outrageous solutions do not get implemented, but may lead to creatively discovering a solution that solves the problem.

The Solution Analysis stage takes a closer look at the solutions developed in the generation phase, and analyzes each solution for feasibility in implementation. The design team should look at all parameters as they relate to the problem statement. For instance, the product might have time constraints that should be taken into account when narrowing down the list of potential design solutions. Additionally, a comparison of the solutions generated is necessary and can lead to determining the most appropriate solution. In the Solution Analysis phase, the design team might find that a combination of solutions is optimum. Once the solution is narrowed down a prototype of the best solution is made, and are analyzed further to determine how favorably the solution solves the problem. Much time is spent in testing the prototype to ensure the design is optimum.

The fourth step in the engineering design process is the Solution Implementation phase. Within this phase of the design process the prototype is developed into its final design and given to the customer for use. Feedback should be obtained from the customer such that future iterations of the design can be made with the necessary improvements.

Throughout the four phases of the design process the design team must keep in mind that design is not a linear process but rather an iterative process. While in the Solution Generation phase, the design team might determine that a closer examination of the problem formulation is necessary; thus, requiring the team to return to stage one of the design process. For instance, another parameter might develop that alters the problem.

During the Solution Evaluation phase the results might not lead to the desired solution and a review of the Solution Analysis phase might be necessary. Additionally, as mentioned with the final design, feedback might be received that suggests changes should be made to the design, which leads the team back to the prototyping phase of the design process.

Not only is the engineering design process taught in the engineering education community, engineers are expected to apply the engineering process to their design initiatives in industry; thus, it is widely utilized in industry and is considered the standard process for a design problem. The National Aeronautics and Space Administration (NASA) outlines the engineering design process they use [26] for design initiatives as an eight step process, shown in Figure 2-6. A comparison can be made between the NASA engineering design processes with the generalized form of the engineering design process depicted in Figure 2-4. Steps 1 and 2, in the NASA design process, fall within the steps of the Problem Formulation phase. Steps 3 and 4, in the NASA design process, fall within the steps of the Solution Generation phase. Steps 5 and 6, in the NASA design process, fall within the steps of the Solution Analysis phase. Steps 7 and 8, in the NASA design process, fall within the steps of the Solution Implementation phase. The final step, step 8, indicates the iterative nature of the process.

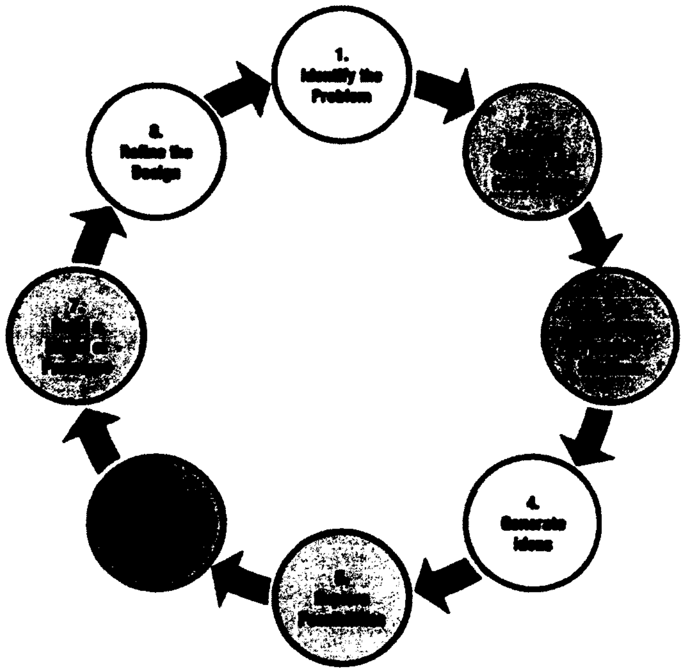

Figure 2-6: Illustration depicting the engineering design process as seen on the NASA website [26].

Another popular version of the engineering design process used in industry is the IDEO design philosophy [27-28]. IDEO [29-30] is a successful design firm that consults for various design projects by taking a humanistic approach to innovation by using diverse design teams to develop products. To begin the design process, the design team collects information on the product by reading research and talking to experts. Once adequate information is gathered, the design group begins the Solution Generation phase. The IDEO philosophy of design is heavily geared toward the brainstorming process. Brainstorming sessions are typically very comprehensive and abide by IDEO's five rules of brainstorming as established by IDEO: 1. Defer judgment, 2. Build on the ideas of others, 3. One conversation at a time, 4. Stay focused on the topic, and 5. Encourage wild ideas [27-28]. A facilitator is used to guide the brainstorming sessions, keeping the team on task and encouraging creativity while discouraging negativity. These intense brainstorming sessions are called Deep Dives [27], where the group dives deep into the design process generating a list of innovative ideas. Once brainstorming is complete, the group looks at the suggested ideas and decides together which are best suited for solving the design issue. If possible, the group will create a mock-up of a few designs or take the best components of each design idea to create one solution. A prototype is then constructed and tested, comprising IDEO's Solution Analysis phase. Various tests are performed on the prototypes, which lead to the final design that is given to the client or customers. Many engineering firms as well as engineering educators, use the IDEO design process as a model for their own success in creating, innovating, and designing.

2.2 Curriculum Design

In the literature on curriculum design, educators identify many aspects of the theoretical approach to the curriculum planning process. However, there is very little written on a structured process to design curriculum [31]. One approach mentioned in the literature encourages educators to consider a novel as a metaphor [32] for writing curriculum. A novel contains exciting, thought provoking, multi-layered situations. If curricula were written in such a manner, students and teachers alike would be more invested in the content. The issue with the approaches discussed in education literature is that there is no clear structure as to how to develop the curriculum content. An article written in the *Journal for Academic Development* [31] identified three approaches to begin a curriculum redesign. The first approach is to "focus on the aims/outcomes" of the course. The second approach is the "graduateness" which identifies, prior to developing the course, what sort of students are desired at the end of the course. The final approach is to identify the educational philosophy associated with the curriculum. Figure 2-7 [31] is a flowchart representation of the three approaches to curriculum design.

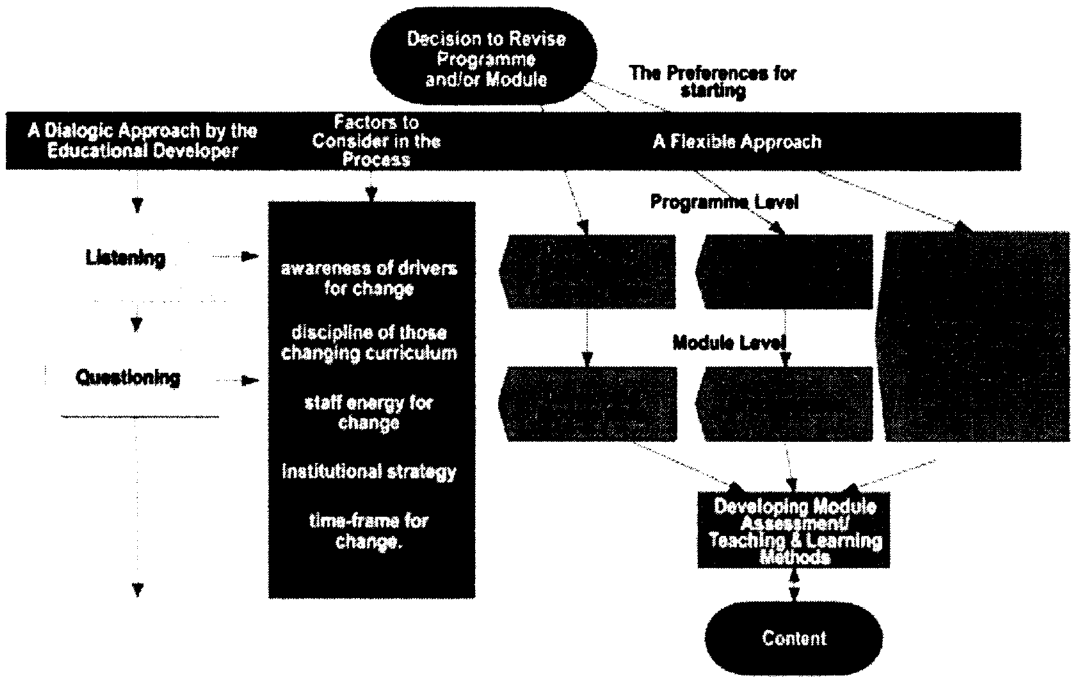

Figure 2-7: Three approaches to curriculum design found in an article in the *Journal for Academic Development* [31].

Instead of a structured process to develop a course, greater emphasis is placed on the philosophy behind the curriculum. A popular model used by educators in developing science curriculum is the 5E Learning Cycle (Figure 2-8) [33]. This cycle represents what curriculum developers should keep in mind when writing curriculum. It links together the concepts of exploration, explanation, elaboration and engagement in a cyclical manner while keeping evaluation as an overarching concept. The 5E Learning Cycle maintains important pieces of curriculum content and should be kept in mind when writing curricula. However, it does not actually provide structure on how to write curricula. The

5E Learning Cycle is more of a model to base pedagogical techniques in curriculum as opposed to designing actual curriculum content.

Figure 2-8: A depiction of the 5E Learning Cycle [34].

It is important to note that the philosophical approach is vital in curriculum development. It does provide a level of perspective, but, relying on a philosophy alone will not write the curriculum efficiently. Creating a structured approach while keeping in mind the philosophy behind curriculum design, will provide optimal curriculum material.

Not all educational curriculum discussions rely solely on the philosophy behind curriculum development. Some structure for curriculum development [35] is found in textbooks on curriculum development (Table 2-1). However, these textbooks lack steps/sub-steps that help to optimize the solution. A noticeable difference between this process and the engineering design process is brainstorming in the Solution Generation stage. Brainstorming ideas is key in creating various solutions and opens a level of dialogue necessary to truly understand the content and scope of the curriculum design project. Additionally, the process does not emphasize the need for iteration.

Table 2-1: Outline of the educational perspective on curriculum development [35].

Operation	Focus	Activity	Resource Base
Analyze	Clarify values Set Goals	Identify purposes Set parameters Outline program Select content Order content	Environmental forces Information sources
Design	Establishing Programs	Develop lessons Select materials Choose instruction strategy Establish management pattern	Knowing about the learning process
Implement	Training for Interaction	Integrate learning Individualizing Instruction	Knowledge of human development
	Application and management resources	Delivery systems, grouping, space, time, focus of learning, climate, personnel roles	Change theory Knowledge of the act of learning
Evaluate	Assessment	Evaluative criteria Student and teacher assessment	All of the above

2.3 STEM Curricula

Successful STEM courses are comprised of various components that align aspects of deep learning and an engaging atmosphere. The curriculum is not restricted to a type of pedagogy; rather, many STEM courses include numerous pedagogical techniques. Within the literature on STEM courses, it is clear that a main component is the use of active learning techniques in various pedagogical forms. The most common form used in STEM courses today is project-based learning (PBL) [11, 16, 36-39]. PBL is a technique that utilizes various projects to drive the fundamentals.

A common trend in STEM education and the PBL technique is the use of a platform for instruction. Using a platform for education, allows for the project-based curriculum which promotes engagement. Platforms provide clear direction for projects. In

STEM classes platforms have been used as educational tools to teach design [11, 16], electricity [36], mechatronics [38], among other topics [37, 39-40]. In the first year program at Louisiana Tech University, *Living with the Lab* [11], the instructors use a microcontroller platform to drive the fundamentals being taught in the courses. The *Living with the Lab* program is a three course sequence that spans the first three quarters for first-year engineering students. Students are taught fundamental concepts of electricity around the microcontroller platform during the first quarter. During this quarter various activities must be completed which require the use of the microcontroller with sensors and the students knowledge the electricity fundamentals. The students, then, move into the second quarter where the microcontroller platform is utilized to teach the concept of mass balance. Student must use their microcontrollers to build a "fish tank" mechanism that controls the temperature and salinity of water. During the third quarter the students are comfortable with the microcontroller and will use the platform to learn about engineering design. Students are required to use the microcontroller and sensors to design, fabricate, and test an open ended project of their choice [11, 40]. Using a platform for instruction is beneficial because it is a driving force that teaches the fundamental concepts. However, if implemented properly, the platform is not the soul of the course. If the platform is removed, the fundamentals are still intact [16]. The platform provides the engaging atmosphere which encourages a deeper more practical understanding of the course.

Some PBL courses do not necessarily have a platform, but rather contain projects based around a particular concept [10, 41-43]. In these courses there is not a central theme of a platform such as the microcontroller propelling the projects but individually, along with the fundamental concepts, there are standalone project(s). A common technique used in PBL courses is to use inquiry-driven projects [44-45]. Inquiry-driven curriculum uses the students' desire to learn more and figure out for themselves how things work. Many courses use a combination of techniques: platform, stand alone projects, and inquiry driven. This can appeal to the various learning styles in the classroom.

Active learning within a STEM class allows for students to be exposed to authentic problems that will increase the level of deep learning. Students not only benefit from deeper learning of fundamental topics, but also are typically exposed to lifelong learning skills such as: team work, presentation/communication skills, independent thought, etc [46]. The teamwork atmosphere is indicative of real-world situations. Whether students are pursuing a degree in STEM, or just taking a STEM course to meet a requirement, they will more than likely have to work in a group setting at some point in their careers. Teaching students to be productive in such an environment will benefit them greatly both personally and professionally. Many projects require time management and diverse perspectives for optimal completion. Introducing a team environment during STEM courses [40] will help provide students with the varying perspectives needed to accomplish tasks as well as exposure to working in such an environment.

A STEM course should provide an active learning environment by identifying fundamental concepts with projects which enhance the learning experience (and do not simply provide an awe factor); these projects could be standalone with the fundamental concept or based on a platform. Being that the "T" in STEM stands for technology, it is important that technology is used in STEM classes. Exposure to various technologies can help propel student interest as well as encourage student inquiry. Keeping the attributes of a STEM course in mind is essential in writing curricula. One would not want to attempt to write/rewrite a STEM course without incorporating projects. Doing so would negate the research identifying the benefits students gain through PBL curriculum. Thus, any STEM curriculum developed should have a heavy basis on the fundamental concepts, provide active learning components whether through a platform or isolated projects, use technology where appropriate, and finally, provide lifelong learning skills.

> "First of all it needs to be important to integrate math as well as bring engineering strateg..."
>
> -Missy Wooley
> K-12 STEM Educator

2.3.1 Examples of STEM Curricula

2.3.1.1 *LaTechSTEP – High School Level Curriculum*

At Louisiana Tech University, the College of Engineering and Science has developed an outreach program, *LaTechSTEP* [13], for area high schools to participate in weekend projects that promote STEM topics. The program encourages learning for transfer by practicing many of the characteristics described by the National Research Council such as increased level of motivation and a focus on the fundamentals [5]. Additionally *LaTechSTEP* takes into account the idea discussed earlier that reaching out to students prior to college level instruction [6] is important in increasing motivation and changing stereotypes towards engineering fields. Teachers and students from various high schools come to the university campus to participate in rigorous activities framed around exciting projects. These workshops are scheduled at strategic times during the year to provide opportunities for deep understanding and discussion of material. Each campus visit builds on the material previously learned; therefore, the time between visits where the students discuss the topic of the project and work on assignments/project as a team is a key aspect in learning for transfer. Three projects [13] were developed to be used in an annual rotation: catapult, truss, and fuel cell. If students attend more than one year, they will have a variety of experiences.

Many high school classes not associated with *LaTechSTEP* conduct a simple catapult project. However, in the *LaTechSTEP* program students are required to delve deeper into the mechanism of the catapult. In a typical class, the students will most likely build the catapult, watch it launch a projectile, and maybe figure out where it would land given an initial velocity provided by the instructor. In the *LaTechSTEP* program, the students not only have to build a catapult, they have to figure out, using fundamental energy balance concepts, the initial velocity, and calculate with minimal error of the location where the projectile will land. This promotes a level of inquiry and forces students to make connections and develop theories on how to determine the initial velocity for themselves. After the students determine how to find the initial velocity of their projectile, they are able to calculate where the projectile will land and in turn see theory match practice – a concept which is crucial when trying to develop a deep understanding of a topic. At this point, the project could be over and students have a good understanding of projectile motion, but the *LaTechSTEP* program takes the task even further. Students take their catapults back to the high school and design and build a catching mechanism. The students' task now is to toss their projectiles across the room in a circle to the other teams participating in the program with no human intervention. This requires an understanding of basic building techniques, fundamental theory behind projectiles, teamwork and collaboration skills, as well as a level of creativity. This provides an atmosphere of excitement and engagement which the students need to develop their learning for transfer [13].

The *LaTechSTEP* program allows high school students to have a unique experience and exposure to engineering concepts through the university setting. A potential danger with this program is that it could be focused too much on the context and does not provide the level of abstraction needed for the students to transfer the information to other contexts, as is cautioned by the National Research Council [5]. However as mentioned in the paper written by Adams et al. [6], since these students are new to the topics the program does provide a level of concrete examples that the students can understand better than if the program was presented primarily in an abstract manner. In response to this, administrators of the program have created a curriculum that maintains a healthy balance between the abstract and concrete with a heavy focus on engagement.

2.3.1.2 *Living with the Lab - College Level Curriculum*

On the college level, engineering instruction has taken vast strides using techniques that encourage learning for transfer in students, specifically in first-year programs. In a typical institution that does not have a first-year program; engineering students have limited exposure to engineering courses until their junior year of studies. However, with a first-year program, freshman students are exposed to the fundamentals of engineering in an atmosphere that encourages engagement. Louisiana Tech University has developed an interdisciplinary first year program based on the pedagogy of inquiry-based learning. The program is called *Living with the Lab.*

The concept behind *Living with the Lab* is that the freshmen students live with their "lab." Each student purchases a microcontroller and a set of tools which they carry to and from engineering class. Throughout the freshman year, the students use their "lab" to learn various engineering concepts. Students typically work in teams, developing some of the soft skills needed of an engineer as well as creating a community of cohorts. The first, second, and third quarter course sequence is based on three key engineering fundamentals: electricity, mass balances, and statics, respectively. These fundamentals are driven by the microcontroller as well as various other projects.

The first topic in the *Living with the Lab* curriculum utilizes the microcontroller platform to teach electricity fundamentals. Each student creates various circuits on the microcontroller breadboard. In their toolset the students have a multimeter which they use to measure components of electricity moving through the circuit. Using these measurements, students develop, for themselves, the equations associated with electricity (i.e. Ohm's law, combining resistors in series and parallel, and Kirchhoff's Voltage and Current Law). This provides an atmosphere for deep learning and full understanding of concepts. If the students do not remember a concept or need to refresh their understanding, they always have the "lab" with them to recreate it at home [40].

Once the students learn about the basic electricity fundamentals, they are tasked with designing and fabricating a centrifugal pump. Because the class is interdisciplinary, it is easy for the students to see direct correlations to mechanical and electrical engineering, but instructors are also encouraged to discuss with students how other engineering fields are applicable to the pump project. This helps to encourage biomedical, chemical, industrial, and other engineering students to take a personal interest in the project by learning some application to their concentration. Students learn basic pump principles which they use to design a pump impeller. Each impeller is printed in the freshman project lab using a rapid prototype machine. This exposes students to different manufacturing processes while creating a sense of accomplishment in seeing their own impeller design created not only virtually through their computer aided design program, but also physically through the rapid prototyping machine. Once the impeller is printed the students are given the remaining parts that will become their centrifugal pump. Students learn about dimensioning and tolerancing by taking parts of the centrifugal pumps to a milling machine and drilling the holes to specification. Exposure to such machines allows the students to experience a manufacturing process that they could easily adapt to different projects. After the pump is fabricated, students test their pumps by lifting water through a testing apparatus. They use the concept of electrical and mechanical power learned previously to calculate the pump efficiency. This project allows students to revisit older concepts and cement them in their knowledge. After the students complete the project they present their pump and findings to the class in a formal presentation, further aiding in the development of teamwork and communication skills [47].

Each quarter the students have a main project that builds on the previous quarter. The first quarter the students build a centrifugal pump. The students take their pump with them to the next quarter's engineering class and use it as part of their second quarter project (designing and fabricating a "fish tank"). The students use the microcontroller and sensors to control the temperature and salinity of the water in the "fish tank." The final quarter the students are given an open ended design project. At this point, students have a working knowledge of the microcontroller and sensors. Students choose a design project based on a "bug list" developed at the beginning of the quarter. Students design, fabricate, and present a working prototype. This project could be anything the students think of as long as it uses the microcontroller and sensors discussed during the course of the *Living with the Lab* experience. This open ended problem gives the students a sense of self motivation and involvement in the project as well as requires transfer of the knowledge learned in previous quarters to help solve their open ended project. Because no project is the same, students are exposed to the various ways the microcontroller and sensors can be used in different applications through their classmates' designs. Examples of past projects [40] are: the "SPOTBOT" where students programmed sensors to assist a weightlifter when the weight gets too hard to lift and no one is available to spot them, "Electronically Assisted Trailer Hitching" which aids the driver in aligning his/her trailer hitch with a trailer given no assistance from someone directing them, and "Eco-Friendly Lighting System" which uses solar power to control the movement of blinds and the brightness of lighting in a room given the lighting conditions outside.

CHAPTER 3

METHODS

3.1 Methodology

The methodology used for this dissertation is a combination of two emerging methodologies in the engineering education community: Ethnography and Action Research [48]. Although these methodologies have been used extensively in other fields, they also have been identified as viable methods for engineering education research [48]. Typically the methodologies have been used in the field of learning sciences. Johri and Olds point out that collaborating with the learning sciences is essential in fostering better innovation within the field of engineering education [49].

First, ethnography is understood to be a methodology where the researcher is immersed in the day to day process being researched. The researcher collects qualitative data by questioning and observing or experiencing the course of action. For the purpose of this dissertation, an interview was conducted with Dr. James Nelson, Dean of Undergraduate Studies, on his influence with the redesign of the freshman curriculum. Additionally, an informal survey was sent to key Louisiana Tech University faculty and high school teachers to obtain perspective on the curriculum design process. Results from the survey are dispersed as quote bubbles throughout the dissertation within applicable sections. The raw data from the surveys can be found in APPENDIX A.

Secondly, action research is combined with the ethnography process in order to evaluate the curriculum design process. Action research is defined as a method that looks to create improvement in current practices. In this dissertation the action research methodology is employed in order to create the framework to improve the STEM curriculum development process. As an active participant in the curriculum development process for various curricula [50-54], the author obtained experiential exposure to the process which allowed for the development of the framework. For further information on the authors experience with curriculum development reference the Vita attached with this dissertation.

3.2 Method Philosophy

Along with the methodology used to develop the framework for curriculum design, the philosophy behind the framework needs acknowledgement. In the education community, there are conflicting views in identifying the product and the customer. Some feel as though education/curriculum is the product and the students are the customer [55-56]. Educators create a curriculum – the product – to provide the students – the customer – with the best possible education preparing them for their futures. Contrarily, many educators feel that the student should not be treated as the customer [57-58]. Some feel the students are the product and society is the customer. Educators work to prepare students to be productive citizens in the society; therein, educators act as the company preparing the product – students – to be ready for the customer – society.

To approach the development of a framework for curriculum design, a clear perspective was necessary. For the research presented in this dissertation, the former was chosen as the focal point for reference. Thus, the students are considered the customer and the curriculum is the product. Using this perspective does not discredit the opposing view; however, to frame the philosophy behind this research the student as the customer and curriculum as the product was more fitting. With this philosophy set, the same principles of engineering design can be applied to curriculum design. The engineering educator has a product – the course – and is told to make it better for the customer – the students.

CHAPTER 4

RESULTS

4.1 The Design Team

Before outlining the framework for curriculum design using an engineering design perspective, it is important to understand who should be involved in the design team. In design, both engineering and curricula, typically the process is done in groups. This is necessary in order to gain a variety of perspectives and talents. For instance, if an engineering company wants to develop a new ergonomic chair, should the team be made solely of the mechanical engineers at the firm, or rather should the design team be consisted of a diverse group of mechanical engineers, industrial engineers, salespersons, and human resources personnel? The IDEO philosophy, discussed previously, chooses the latter [27-28]. Additionally research has shown that diversity within a group is beneficial to the quality of innovation for the design [59]. Keeping this research in mind, the same approach should be taken with curriculum design.

Hypothetically, educators might be tasked with redesigning a mathematics course for college level instruction. The curriculum design team for this course should not only consist of mathematicians, but also should include instructors from other disciplines, such as engineering and physics instructors. It might also be beneficial to the curriculum design to include a non-math oriented instructor, such as a history professor, to gain additional perspective. Maintaining a level of diversity will allow for the various perspectives of people involved in the course.

A non-STEM instructor could yield a similar perspective as those students not specifically interested in the STEM course. Additionally, having a non-STEM instructor as part of the curriculum development team might open doors for multi-disciplinary projects and connections in the course that might have otherwise been overlooked. Making the course multi- and interdisciplinary creates opportunities for deeper connections to the material and in turn promotes deeper learning. Not only should the team be composed of instructors at the curriculum's level of instruction, but if possible educators that teach the higher or lower level courses in the discipline. Having these individuals involved in the design process could yield better connection with prior and/or future content. Thus, it is beneficial to the STEM curriculum design process to have a diverse group of individuals involved in the design process.

4.2 Developing the Framework

Now that the "who" is establish for the curriculum design process, the "how" can be outlined. Using the engineering design process as the perspective for curriculum design provides a structured methodology to the design of curriculum. It benefits in optimizing the results of the curriculum design in an efficient manner. Figure 4-1 shows a parallel comparison of the curriculum design process with the engineering design process.

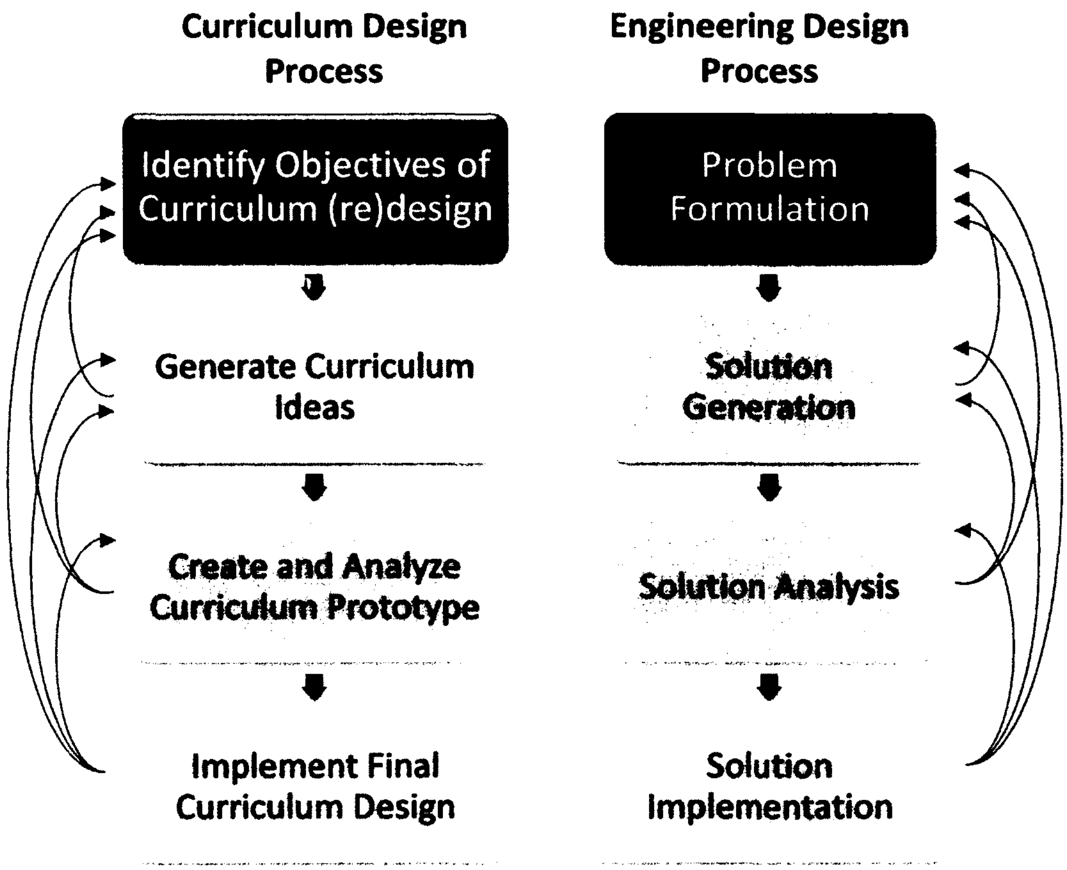

Figure 4-1: Parallel comparison of the curriculum design process and the engineering design process.

As you can see the four main steps in the engineering design process can be analogously linked with the steps in the curriculum design. Relating the design of curriculum to engineering design can be useful in creating an optimum end result. In engineering, a firm makes a product for customer use. This scenario can be related to curriculum design. Educators (the firm) present curriculum (the product) for the students (customers) to learn. The engineering firm wants to improve their product for their customers. STEM educators want to improve the curriculum for students. STEM educators want students to have deep understanding of content and gain the ability to learn for transfer; thus, engaging pedagogies are desired to make curriculum a better product for the "customers." Therefore, the design team formulates the problem statement, generates a new or revised curriculum for piloting and analyzing, which can be evolved into the final curriculum.

4.2.1 Problem Formulation

In order to develop an innovative approach to curriculum that includes all the aspects of engagement needed for deep learning, educators must develop a clear understanding of the goal for the curriculum design. This process relates to the Problem Formulation stage of engineering design. Using the more philosophical approach that educators have outlined can be beneficial in this stage of the design process. When trying to define the parameters of the STEM course, the design team should address such questions as: What level of instruction is the curriculum addressing (i.e. Elementary, Secondary, High Education, etc)? What are the standards the course must abide by? How in-depth should the curriculum be written (i.e. lesson plans, instructor notes, student materials)? What material should be included in the course? How should interactive components be woven into the curriculum? What affect does the pedagogy associated with the curriculum have on the students? Discussing these questions at the beginning of the design process can help lead the focus of design. All aspects of the purpose for the curriculum design, the manner by which it should be presented, and the student need for the content, should be assessed when formulating the problem statement. Additionally, the design team must look at aspects such as: presentation of the material, type of pedagogy used for the curriculum, depth of material development, time allotted to teach curriculum, age of student, etc. Once the theoretical questions and curriculum parameters are addressed the curriculum design team can develop a well formulated statement which will guide them to the intended curriculum goal.

4.2.2 Solution Generation

The second step in engineering design is Solution Generation. As it relates to curriculum design, this phase includes brainstorming ideas for the curriculum that will yield the intended goal described in the problem formulation phase. Within this step are three categories for brainstorming: Content, Attributes, and Compilation.

4.2.2.1 *Content*

When brainstorming for content, the design team must keep in mind the goal of a design project is to better provide the product (the curriculum) to the customers (students). The educator must maintain a level of rigor such that the fundamentals are the basis of the content, while also providing applications that are relevant to the students, the active learning component. Brainstorming with the design team is essential in creating the most innovative approach to the curriculum content. The brainstorming sessions will lead into developing the flow of the curriculum content, the projects, and applications that drive the fundamental concepts. Knowing that the fundamentals are the basis of any STEM course, the fundamental concepts should take on that role during the brainstorming. The design team should identify all the fundamental concepts for the particular curriculum. The fundamentals do not necessarily have to be listed in order of how they will be taught, but rather just listed. The order by which they will be taught in the course will evolve through the design process once the other learning components are identified. Fundamental concepts can be identified in various ways such as referring to ABET requirements on the collegiate level, grade level expectations (GLEs) on the K-12 level, or simply looking at textbooks typically associated with the curriculum to find reoccurring topics. Once the fundamentals are identified, the design team can begin brainstorming ideas for the platform, active learning projects, and technology. Each member of the design team collectivly and/or individually should develop numerous ideas on the active learning projects that can be attached to fundamental topics. This process can be done virtually through email or portals such as Google Docs, but it is recommended that the brainstorming be done together in one room. It can be beneficial to write the fundamentals on a board where the various active learning components can be added on the board underneath the fundamental concept [60].

> **"Start with the [illegible] interesting applic[illegible] hardware and softw[illegible] support applications; A[illegible] "platform"; Think about [illegible] fundamentals are to be taught; [illegible]storm on ways that the "pla[illegible] [illegible] used to support fundamentals [illegible] applications and larger [illegible] to make sure everything works; [illegible] the content."**
>
> **-David Hall**
> **[illegible]ciate Professor, Program Chair, MEEN**

4.2.2.2 <u>*Attributes*</u>

When writing the curriculum, attributes of the learner must be considered in addition to the delivery of fundamental content. Communication, team work, and lifelong learning skills are critical to the design of any new STEM curriculum. Methods of incorporating these attributes into the curriculum should be brainstormed while developing fundamental topic ideas. Not all components of the course can address each attribute; thus; it is critical for the design team to identify where they can be appropriately integrated.

4.2.2.3 *Method of Compiling*

In addition to the content in the course, a major component of curriculum design is how the course material should be compiled. The form of the new curriculum when it will be disseminated to the instructors of the course as well as the students (i.e., a book of notes, online curriculum, textbook, etc.) is key in the successful development of curriculum. The scope to which the curriculum will be designed should be defined in the problem formulation phase. Identifying the scope in the previous step in the design process allows for a clear focus on the materials to be compiled which will help in the brainstorming process. If, in the Problem Formulation phase, the design team decided that the curriculum development will include student notes, teacher notes, and assessment rubrics, then the brainstorming for compilation of these materials will be different than if the design team set the scope as simply writing teacher master notes.

The design team should identify the software that should be used to create the curriculum: MS Word, MS OneNote, MS PowerPoint, etc. Given the different perspectives within the design team, exposure to a variety of compilation programs will provide various suggestions to how the notes should be compiled. The team can brainstorm various templates for the master notes, student notes, etc., if they are necessary as identified in the scope of the problem. Additionally, suggestions of portals to hold the curriculum such as a host website, Google Docs, email, only hard copies, etc., are made in this stage. Someone in the design team might know of a new technology or software that will aid in compiling the material. It would be easy to assume for curriculum design projects, the design team should always create a website to hold the information; however, depending on the scope of the problem and the skills of those involved in the design other methods may be more advantageous for the given project. Thus, brainstorming ideas which will be narrowed down and implemented in the next phase will prove beneficial to the design team.

4.2.3 Solution Analysis

After adequate brainstorming time (adequate time is determined by the design team), the curriculum design process can transition into creating and testing the curriculum prototype. In terms of the engineering design process this is the Solution Analysis phase. This phase narrows the solutions generated by the previous stage and begins to formulate curriculum. As this relates to engineering design a solution is developed by choosing the best design or combing the best aspects of ideas to create a prototype. Since there were two areas in the Solution Generation phase, this third phase will also look at both of those areas. Although in this dissertation the two areas of content and compiling are separated, it should be noted that they are generally completed in a parallel manner. As decisions are made on the content, the compilation side will be affected as well. Changes will most likely be made with the manner of compilation if changes are made with the content.

4.2.3.1 *Content*

At this point in the design process the design team assesses the various active learning components identified in the solution generation phase. The design team studies aspects of the project as they relate to the problem statement identified in the first step of the process. The team should assess which design alternatives for the active learning components will provide the results desired for the curriculum: which provide the best deep learning opportunity for the students, which are feasible given the resources allotted, which are feasible given the restraints in time/length of the course, which alternatives provide the desired level of rigor in the course, and so on. If possible, the design team develops a few of the best active learning alternatives to the specific fundamental concept then evaluates them to determine which is best or if a combination of the alternatives yields the best result. If it is not possible to develop varying alternatives, the team should fully assess the alternatives brainstormed for each fundamental concept to determine the best alternative. The lessons will be developed into a prototype which will be tested. If the alternative chosen does not meet the desired standards, the iterative nature of the process will be utilized and a different active learning component can be developed and tested.

4.2.3.2 *Method of Compiling*

Similar to developing the best components for the curriculum content, the design team looks at the ideas brainstormed for the compiling the content. Given the skills and abilities of the design team as well as the scope of the curriculum design project, the alternatives for compiling materials are assessed and decided upon.

4.2.3.3 *The Prototype*

After assessing the ideas generated in the previous stage, the design team develops a layout of curriculum topics, projects/applications, and method of documenting the curriculum, creating a prototype curriculum. This prototype would include the timeline for the curriculum as well as documented versions of the projects and if needed, instructor notes, lesson plans, and student materials. The development of the timeline evolves along with the fundamental topics and the active learning components associated with the topics. A seamless flow of active learning components and fundamentals are developed in a logical manner design to benefit the students and encourage deep understanding. The fundamentals and active learning should build on each other throughout the course.

Like engineering design, this process is iterative and the initial flow of topics can be reassessed and changed during the testing of the prototype. For instance, as the lesson development evolves, the template used for compiling the lessons may change. Similarly some of the projects used to drive the fundamental concepts might need adjustment. This can require a review of the ideas in the brainstorming phase or another brainstorming session altogether.

When creating the prototype, it is typical for the design team to divide and conquer the various lessons. Each person should select a group of lessons to develop individually. Once the lessons are drafted, the team can trade lessons and review them for any needed improvements. This helps in ensuring the necessary information is in each lesson as well as ensuring the quality of the content.

4.2.3.4 *Testing the Prototype*

The process for testing the curriculum is conducted through a pilot phase of the course. The curriculum is taught in controlled environments, possibly by people involved in the design process. Feedback during the pilot phase, from both the instructor and the students, is used to assess the accuracy of the curriculum design and its effectiveness of solving the problem as stated in the Problem Formulation stage. Testing the prototype will inherently result in

> **"Kinks are worked [illegible] groups; Projects are revi[illegible] materials are improved (drop [illegible] things, add others)."**
>
> **-David Hall**
> **Associate Professor, Program Chair, MEEN**

more iterations of refining the prototype curriculum. Having this component of the design process is essential in creating the most optimum solution. The testing phase allows for holes in the design to be exposed; thus, allotting for a completely fluid curriculum.

4.2.4 Solution Implementation

Once the pilot phase is complete, the final design of the curriculum is ready to be presented to more "customers" (students). It is should be noted that the pilot phase can be executed as many times as neccessary; the design team should use their discretion to determine the length of the pilot phase before transitioning to the final design. The final design is a modified version of the prototype with the adjustments made from the testing process during the Solution Analysis phase. The term "final design" is somewhat misleading because in many engineering designs you never truly reach a final design. Products, in general, always have room for improvement. This is also true with curriculum design. With changing societal attitudes as well as new technologies and pedagogical techniques, improvements can always be made. This is a major connection between curriculum design and engineering design: they are both iterative processes. Inside each phase, the design team may need to revisit an earlier phase in order to achieve the best results.

One of the most vital elements in implementing the final design is making sure the instructors are comfortable with the new curriculum. Professional development programs such as workshops, seminars and discussion sessions, consulting, mentoring and partnering arrangements, and learning communities help to achieve this element [61]. Each professional development program has pros and cons. The right professional development program is dependent upon the curriculum written and the participants of the professional development program. In most cases, providing an incentive for faculty/instructors to participate will increase attendance and enthusiasm for participation [61]. This incentive could take the form of professional development money, certification, or something as simple as free food; again, it depends on the audience for the professional development.

The need for getting instructors on board with the new curriculum is essential to the success of the design. Without proper introduction to the new curriculum design, the instructor might feel a lack of confidence and overwhelmed with the material exhibiting a negative attitude towards the course in the classroom [32]. This would result in the students not benefiting from the new curriculum. If the instructors are introduced to the curriculum in a way that encourages them to learn it, they will then be inspired to teach the course and in turn inspire the students to learn the content [32].

In the Solution Implementation stage, the design team should address the sustainability of the curriculum. Various economic influences can impact the maintenance of the curriculum. Additionally, addressing sustainability issues can contribute to the need for the next iteration of the design.

4.2.5 Curriculum Design Framework

Figure 4-2 is a pictorial representation of the curriculum design framework. The main phases as they are found in the engineering design process are established as the overarching phases of the curriculum design framework. The sub steps are written specifically for STEM curriculum design. With any engineering design based approach, iteration is important; therefore iteration arrows were placed to show areas where iteration may benefit the design.

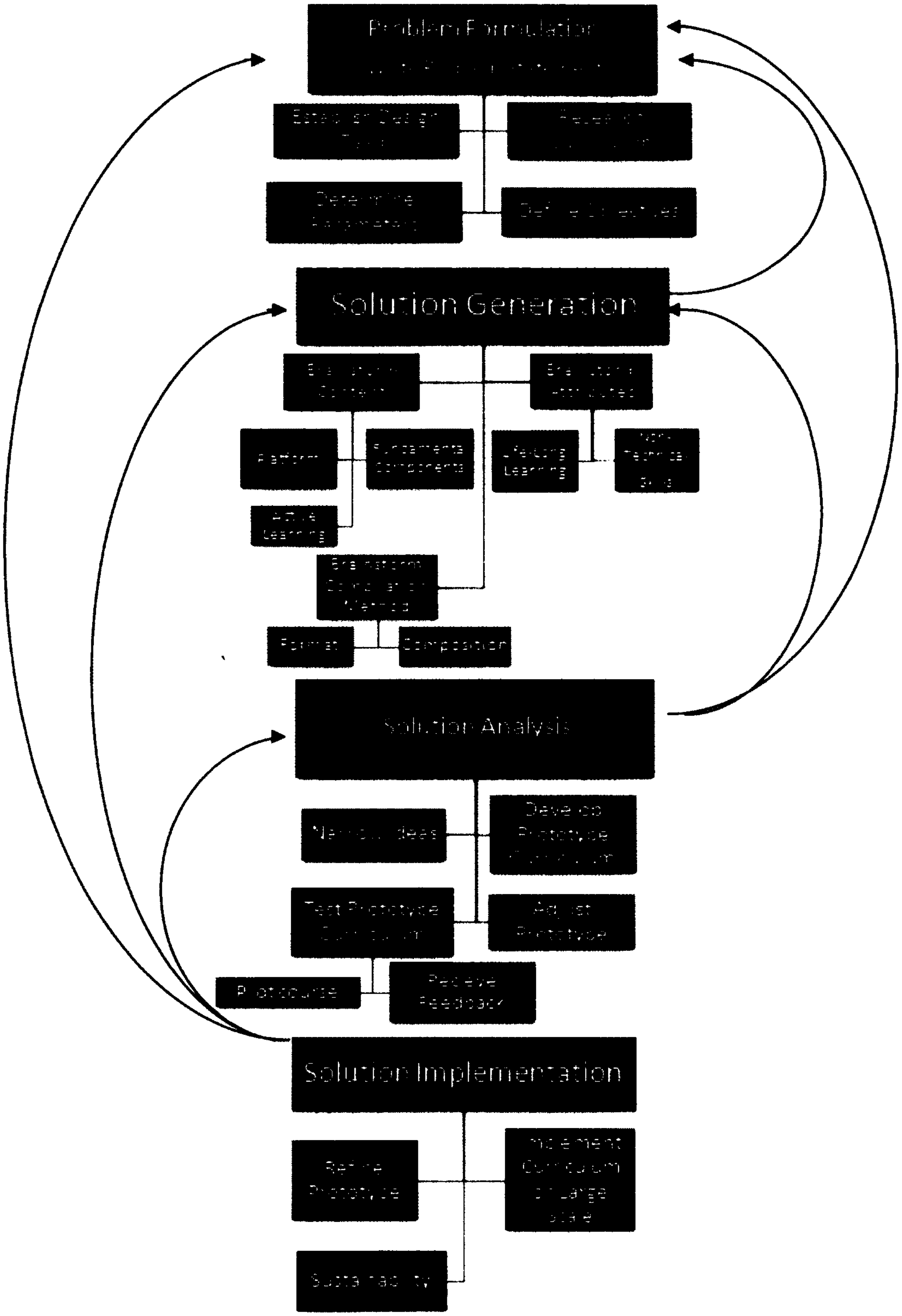

Figure 4-2: A pictorial representation of the curriculum design framework.

CHAPTER 5

DISCUSSION

5.1 Introduction of Examples

Various members of the College of Engineering and Science (COES) faculty at Louisiana Tech University have used some form of the engineering design process to develop STEM curricula on the college and the K-12 levels. Some courses developed were approached specifically with the engineering design process in mind (NASA-Threads, Cyber Science) while others (Integrated Engineering Curriculum) naturally took the approach given the engineering educators developing the curriculum. Not only at Louisiana Tech University has curriculum design been approached with an engineering design perspective, but engineering educators from other universities have acknowledged the benefits of using the engineering design to approach curriculum design [62-63]. The following sections will take a closer look at NASA-Threads, Cyber Science, Louisiana Tech University's Integrated Engineering Curriculum, Penn State's Mechanical Engineering Curriculum, and Brigham Young University-Idaho's Capstone course's curriculum design/redesigns.

5.2 NASA-Threads Physics Curriculum

An example of using engineering design to approach curriculum design is the NASA-Threads high school physics course created by various faculty at Louisiana Tech

University. Engineering faculty were tasked with redesigning a physics curriculum on the high school level by making it more hands on and project-based. The project leader, a mechanical engineering faculty member, approached the design task with the IDEO philosophy in mind [28]. Knowing that a diverse team is ideal for design [59], the leader assembled a group consisting of four mechanical engineering faculty members, one electrical engineering faculty member, one mathematics faculty member, one graduate student in engineering education, and three high school physics teachers. This diverse group leant itself to many diverse perspectives towards the curriculum. The high school teachers were able to educate the university faculty on the needs of the instructor as well as the high school student. The faculty members composed the necessary content of the course while giving the curriculum an engineering context.

5.2.1 Problem Formulation

To begin redesigning the physics curriculum, the team met to assess the true goal of the curriculum redesign and formulate the problem (Figure 5-1). The team researched various pedagogies, as well as current physics curriculum instructional techniques. The team held lengthy discussions in order to determine the full scope of the design project, including how the content should be developed and distributed to teachers, what topics should be presented, as well as how the course should be designed in respect to the students' needs. Ultimately the team decided that the course should be a stand-alone curriculum not dependent on a textbook. Rather the design team would create a set of instructor and student notes that would replace the textbook. In addition to the format of the materials, the problem statement also included the pedagogical approach to the course a fundamental-based course that is driven by various projects. The team also decided to use a platform-based approach for the course. The platform used for the course is the Parallax BOE-Bot microcontroller. Identifying the use of the microcontroller at this staged helped in brainstorming the various projects associated with the curriculum. The team also felt that using the microcontroller technology would act as a "hook" for the students to be interested in the material. During the Problem Formulation phase, the name of the course was coined, NASA-Threads, after the funding agent, NASA. The term "threads" emphasized the idea that the fundamental concepts and projects would be seamlessly woven together throughout the course [50].

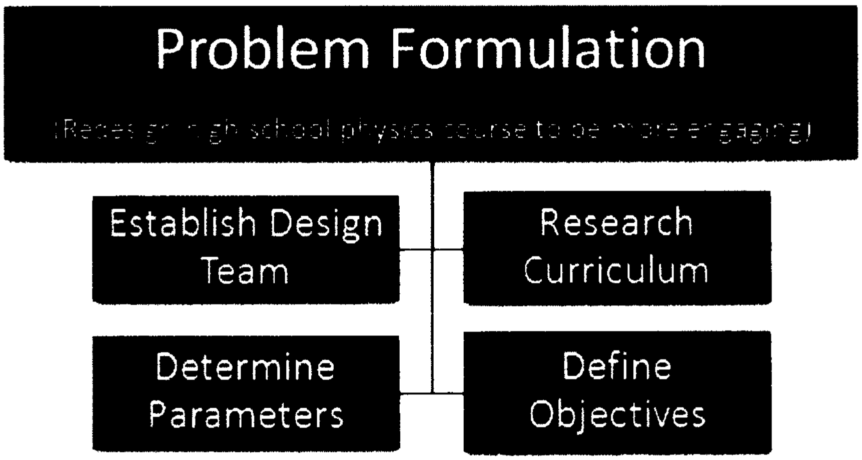

Figure 5-1: Problem Formulation stage of NASA-Threads curriculum design.

5.2.2 Solution Generation

Once the problem was clearly formulated, the design team began the solution generation phase (Figure 5-2). Key fundamental concepts for a physics course were identified and written on a white board. Each main concept was broken down into sub-concepts. Then the team wrote, both individually and collectively, on sticky notes ideas for projects related to the concepts and posted them on the board. This session yielded many ideas for projects. Additionally at this stage, the design team brainstormed the method by which they would compile the materials.

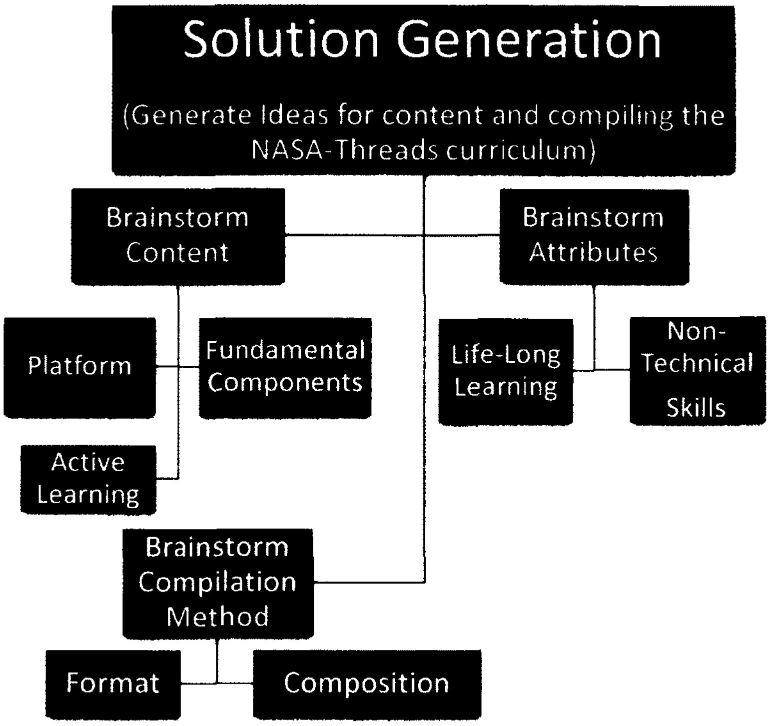

Figure 5-2: Solution Generation stage of NASA-Threads curriculum design.

5.2.3 Solution Analysis

After the brainstorming process was complete, the team had a diverse grouping of topics, concepts, and projects for the new curriculum. The team moved into the solution analysis phase where the curriculum components were narrowed down and further developed (Figure 5-3). At this point, the team decided on the flow of material. Knowing that many of the projects were based on the microcontroller, the team decided to take a nontraditional route and start the physics course with the electricity and magnetism unit as opposed to typical physics courses in high school that begin with work and mechanics. Starting with electricity and magnetism would provide the necessary background for the students to understand how the microcontroller works. After the electricity and magnetism section, the course could easily transition into work and mechanics. For instance, after learning about electrical power through measurement, the students could make the transition to mechanical power, an observed quantity, more easily. The team knew that servos connected to the microcontroller could aid in making this transition more smoothly for the students than a traditional physics curriculum. After the work and mechanics unit, the team placed the light and optics unit followed by the waves and sound unit.

> **"Developing a full [illegible] designed to stand-al[illegible] is a significant undert[illegible] volume of material, inc[illegible] [illegible]phic aids, lesson plans, [illegible] [illegible] sets, quizzes, and tests w[illegible] [illegible]ficant. Probably the biggest design [illegible] was to maintain a high level of [illegible] activity-based learning, while [illegible] full physics curriculum in a [illegible]."**
>
> -Marvin Nelson
> K-12 STEM Educator

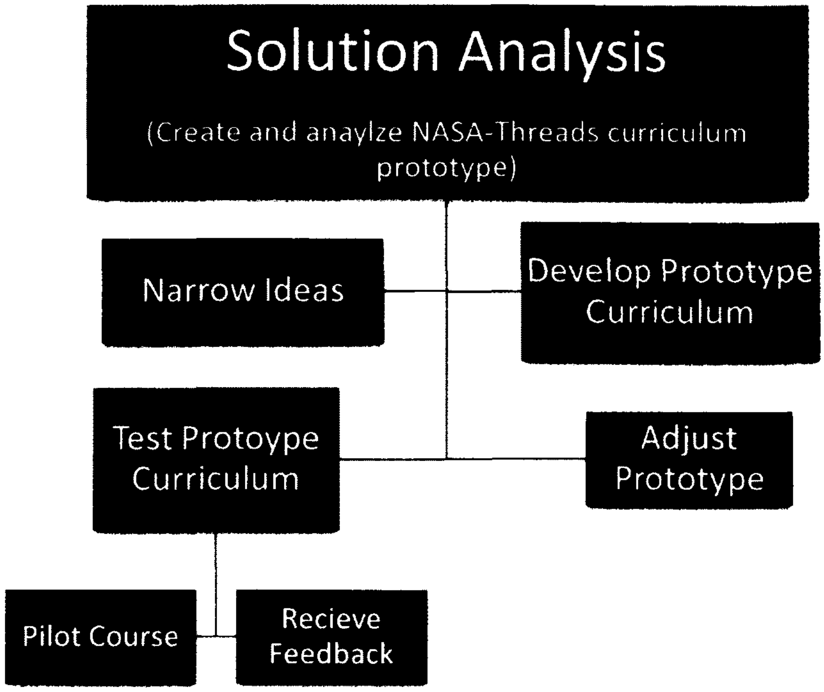

Figure 5-3: Solution Analysis stage of NASA-Threads curriculum design.

5.2.3.1 *Creating the Prototype*

Once the flow of topics for the curriculum was determined, the team assigned sub groups different units to develop. Developing the units was a key component of creating the prototype of the course. Each sub-team created lesson plans and instructor notes for the fundamental concepts and the projects. The instructor notes contained complete descriptions of the fundamental concepts, example problems, suggested homework problems, in addition to project instructions. After all the units were fully developed, the team compiled the lesson plans and instructor notes. Finally, a student worker created student version of the notes based off of the instructor notes.

5.2.3.2 *The Prototype*

The resulting prototype developed by the design team is a flow of physics fundamentals integrated with active learning components. The prototype curriculum uses a microcontroller platform to emphasize the fundamentals of physics. The course consists of four units: Electricity and Magnetism, Work and Mechanics, Light and Optics, and Waves and Sound. Within each of the four main units are numerous active learning components, most using the microcontroller and others as standalone projects. Figure 5-4 is an example of the lesson plans and master notes developed by the design team [51]. The prototype of the curriculum available on the NASA-threads website consists of lesson plans, master notes, homework sheets, tests, quizzes, and any other additional supplemental material all developed by the design team [64]. A more detailed description of the NASA-threads prototyped is found in APPENDIX C.1.

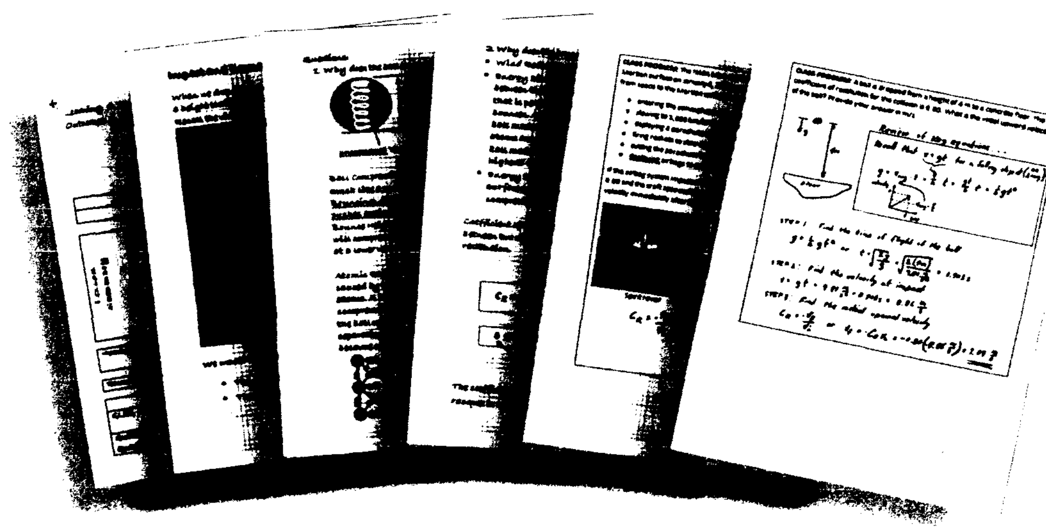

Figure 5-4: Example of the prototype lesson plans and master notes developed by the design team [51].

5.2.3.3 *Testing the Prototype*

After the curriculum prototype was developed, it was uploaded to a website and ready for testing. Teachers and students both were able to access their material through the site. Initially, the three high school teachers on the design team tested the curriculum at three different high schools in the region. Using the high school teachers that helped in the development of the curriculum allowed for piloting the curriculum in a controlled environment. In the initial year, the design team obtained constant feedback from the three instructors on the adjustments needed for the curriculum before a full implementation [50].

5.2.4 Solution Implementation

After the pilot year, necessary changes were made to the curriculum, which was then used by 15 regional high schools. Throughout the second year roll out, feedback was still collected in order to make improvements to the curriculum. This refinement is shown in the engineering design process through its iterative manner. The course will never truly be complete because there is always room for improvement, new technologies and new project ideas. Following the second year roll out of the course, additional schools were added to the third year implementation of the curriculum (Figure 5-5).

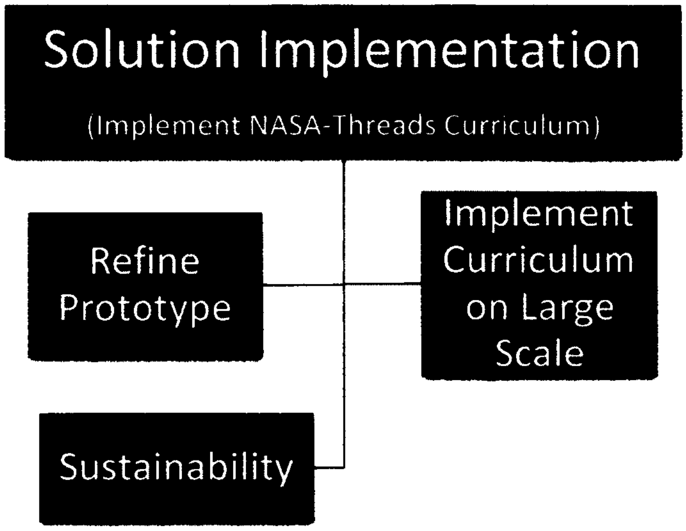

Figure 5-5: Solution Implementation stage of NASA-Threads curriculum design.

In order to present a new curriculum to instructors who typically teach a course in a different manner, introduction to the new curriculum was needed. For the NASA-Threads curriculum, years two and three were preceded by professional development workshops for the high school teachers teaching the new curriculum. Using the workshop method was decided upon due to the need of addressing multiple projects associated with the curriculum in a concentrated time span. The workshops were approached in an interactive manner. The teachers experienced a fast-paced version of the course within a two week workshop period. Each school was asked to send a physics instructor as well as an additional instructor. The additional teacher could serve as support throughout the workshop as well as throughout the school year. At the workshop,

> **"For teachers that [illegible] them in the students' [illegible] them to experience what [illegible] will experience. They had [illegible] ideas and questions that their [illegible] will have. It is important for [illegible] struggle with material from time to [illegible] remind them where their [illegible] are coming from."**
>
> **-Missy Wooley**
> **K-12 STEM Educator**

the curriculum design team presented topics and projects from the curriculum. The workshop participants were tasked with learning the microcontroller platform as well as most of the projects in the course. This workshop proved to be a rigorous process; however, it allowed the teachers to experience the curriculum through the eyes of their students. This experience helped the teachers in understanding the student perspective of the course. Additionally, the design team encouraged the workshop participants to provide feedback, criticism, and comments, on the curriculum throughout the workshop. This feedback helped in refining the curriculum as well as creating an atmosphere where the instructors felt like an integral part of the design process. Throughout the workshops surveys were given to the participants to assess its effectiveness. The results of the surveys were published in a report submitted to Lincoln Parish Schools [65]. Specifically, the results from the final evaluation surveys which were given at the conclusion of the workshops can be found in APPENDIX C.2.

5.3 Cyber Science

Cyber Science is another course developed by Louisiana Tech University COES faculty with aid from key COES associates. This course came into fruition following the NASA-Threads curriculum; therefore, the process used for developing the curriculum was conducted in a similar manner. The course is loosely based on the Cyber Discovery Camp curriculum that Louisiana Tech University faculty developed and hosts each summer for rising K-12 sophomores [66]. Key components in the camp are robotics, computer science, cryptography, history, and political science. Modified versions of these components were used to create the backbone of the Cyber Science curriculum.

The design team for the Cyber Science curriculum consisted of the integral members of the Cyber Discovery Camp team. Faculty from multiple disciplines composed the design team: 2 engineering, 3 computer science, 1 political science, and 1 PhD student in engineering education. The diversity of the team not only provided experts in each of the three main course components (Robotics, Computer Science, and Political Science), but also, like the framework establish previously mentioned, allotted for varying perspectives and opinions to create a refined, diverse multi-disciplinary curriculum.

5.3.1 Problem Formulation

Much like NASA-Threads, the design team established the goal of the curriculum by determining the needs of the school system as well as the course content objective. Ultimately, the course content objective was to create a multi-disciplinary approach to a curriculum that will better educate students on cyber related issues. The school systems wanted a course that would teach the students computer skills in an engaging manner. By framing the course around cyber issues, it was easy for the design team to fulfill the school systems' needs. The design team knew the targeted schools were the same as the NASA-Threads schools; so it was determined in this phase that a similar level of material development would be provided to the instructors: lesson plans and master notes, all available via an internet database (Figure 5-6).

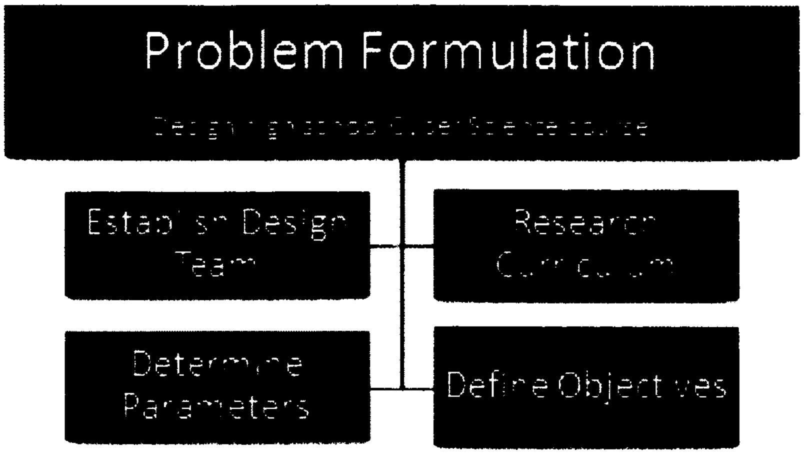

Figure 5-6: Problem Formulation stage of Cyber Science curriculum design.

5.3.2 Solution Generation

The Cyber Science course differed from NASA-Threads in that Cyber Science was a design of a completely new course without any reference to textbooks or GLEs. Rather the design team used the Cyber Discovery Camp curriculum as reference, as well as brainstormed what they felt should be the fundamental concepts taught in the course. The design team looked at the three main components of the course: robotics, computer science, and political science. They brainstormed ideas for fundamental concepts in each of those areas. Numerous ideas were developed during this phase including robotics competitions and projects, computer science fundamentals, political science concepts that relate to cyber issues, as well as methods to incorporate computer skills into the topics.

Also during this phase of the design process, the team brainstormed ideas on the layout of the course. They looked at whether the days should be a combination of all the topics, having a topic of each component presented or whether each day should consist of a single component. Another idea proposed was to teach the course as three separate units where the first unit would be robotics, then computer science, followed by political science (Figure 5-7).

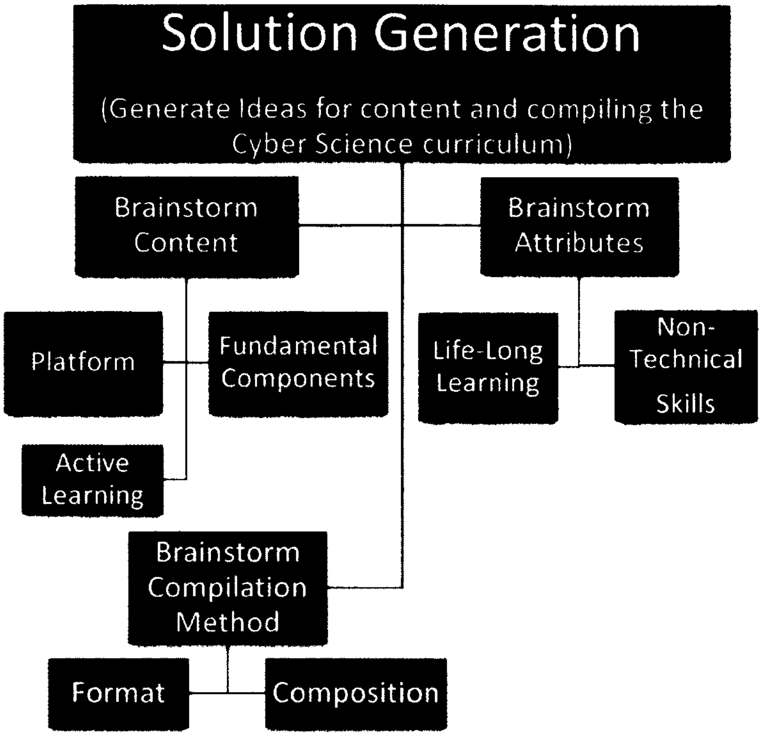

Figure 5-7: Solution Generation stage of Cyber Science curriculum design.

5.3.3 Solution Analysis

Now that the design team generated plenty of ideas for course topics, it was time to narrow them down to fit into a typical K-12 course (Figure 5-8). The design team decided on the layout and time line of the course, which would be most beneficial to the students if the three major components were integrated together. The design team felt the best method of seamless integration of topics was to allot a day for each component. Table 5-1 maps the breakdown of the components for a typical week in the Cyber Science course.

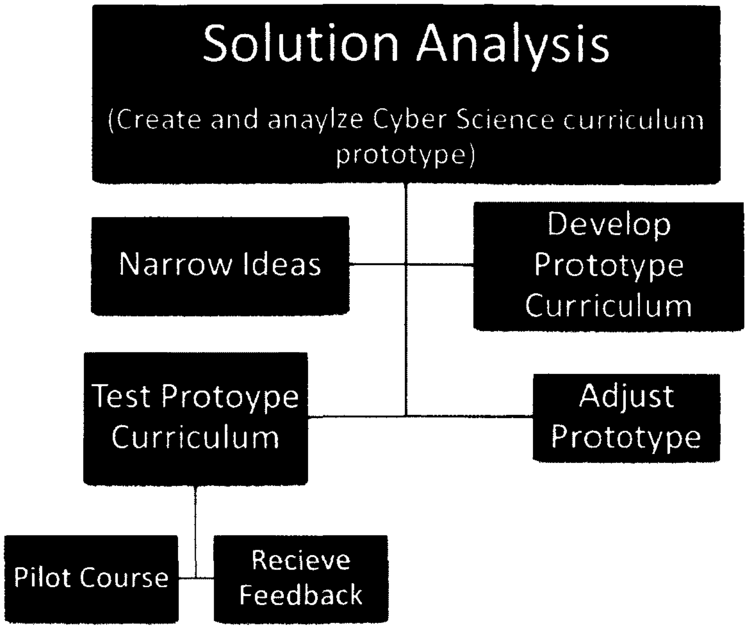

Figure 5-8: Solution Analysis stage of Cyber Science curriculum design.

Table 5-1: Mapping of the content for each day in the Cyber Science curriculum.

	Monday	Tuesday	Wednesday	Thursday	Friday
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

The team felt that starting the week with a robotics day would serve as hook to get the students attention and interest in the course material. Computer science section builds upon the previous day's robotics material or introduces something new associated with the robotics topic. Next, the political science component addresses cyber issues with a liberal arts approach. Because the main three components of the course are addressed at the beginning of the week, the remaining days are utilized for computer skills and projects. Students learn basic computer application skill using a cyber context and material discussed from earlier in the week. For instance, if the political science assignment for the week was to write an essay, students would learn about MS Word and how to use it to their advantage when writing the essay. Likewise, in the computer science section of the course, the students are introduced to flowcharts the students will learn MS PowerPoint to create flowcharts that describe the robotics program they wrote or are writing for their robotics assignment from earlier in the week. Instructors use the last day of the week to work on projects or use it as a catch-up for material not covered fully. Also, the design team felt that having this "flex" day provides the instructors time in the schedule to discuss the week's material and help make connections between the topics.

5.3.3.1 *Creating the Prototype*

Once the flow of topics was determined, the team divided into groups to develop the curriculum materials. The engineering faculty and PhD engineering education student worked on developing the robotics components. The computer science faculty developed the computer science components, and the political science faculty created the political science components. When applicable with the specific core content, the respective design team member wrote lessons that comprised the computer skills section of the curriculum. The design team posted the lessons in an online repository. This repository allowed for easy access to the written lessons where the design team could look over the material for accuracy as well integrate the previously written material in future lessons. Also, the repository aided in identifying the holes in the curriculum, i.e. which lessons were overlooked, which lessons are incomplete, etc.

5.3.3.2 *The Prototype*

The resulting prototype is a 16 week, truly multi-disciplinary course. The design team was able to integrate the use of robotics, computer science, and political science to create a course that will not only teach computer skills, but also educate students on the emerging field of cyberspace. The first week of the course is a good introduction to the material that will be covered throughout the curriculum. The robotics lesson, introduces the students to the BOE-Bot platform, basic programming skills, and terminology. The computer science lesson the next day, introduces the students to flow charts and control flow. Learning this topic will help the students in all their programming components as well as help them to obtain a good basis for the computer science topics. Following the computer science component, the political science lesson takes a philosophical approach to the course and challenges the students to reflect on what the word cyberspace really means. The instructor prompts the students to create a list of cyber related words. Students are then tasked to pick one of the words, research it using credible sources, and then present their results using MS Word. To complete the assignment, on Thursday, students are introduced to MS Word where they learn basic MS Word tools as well as the different formatting capabilities of the program. Students are encouraged to present their material in a creative manner. Friday is then used as a project day for the

> **"…structure/leng[illegible] main outcomes of the [illegible] Through the pilot we we[illegible] determine in many cases wh[illegible] faculty feel can be accomplish[illegible] a set amount of time is not what [illegible] be done in that environment. We [illegible]ved excellent feedback on [illegible] of topics so that the [illegible] better received them.**
>
> **-Travis Atkison**
> **Assistant Professor of Computer Science**

robotics component of the course. Students learn about the servos and get the opportunity to program the BOE-Bot to navigate around an object.

Many of the weeks are formatted in a similar way with the relation of various components from lessons to subsequent lessons throughout the week. Some robotics projects the students do in the course are maze navigation, control the BOE-Bot using keyboard input, navigation of a course using light detection, a "mine" finder, and others. Some computer science topics discussed in the curriculum are binary numbers, understanding algorithms, recursion, sorting, networks, in addition to many others. Some political science topics in the prototypes are security, pros and cons to cyberspace, digital natives versus digital immigrants, and ethics.

5.3.3.3 *Testing the Prototype*

The design team took a slightly different approach to the testing of the cyber science curriculum prototype than they did with the NASA-Threads curriculum. The NASA-Threads prototype was initially piloted with only three schools with instructors who worked to help design the prototype. The cyber science prototype, on the other hand, was piloted with 6 regional high schools without teacher input. Because the instructors were not initially involved in the design process, teachers were asked to attend a summer workshop held prior to the school year. The workshop would familiarize the teachers with the material as well as involved them in the design process. Feedback from the workshop helped the design team refine the prototype prior to piloting the curriculum.

5.3.4 Solution Implementation

Because the curriculum prototype is currently in the piloting phase, the final design has not been completed. Following this initial prototype year, the design team intends to make improvements to the curriculum based on instructor feedback. The design team will host another summer workshop for current and new teachers of the curriculum to attend. The second year will also serve as a pilot year to ensure the curriculum is written efficiently. The following year will consist of the summer workshop after which the design team intends to roll out the final design (Figure 5-9).

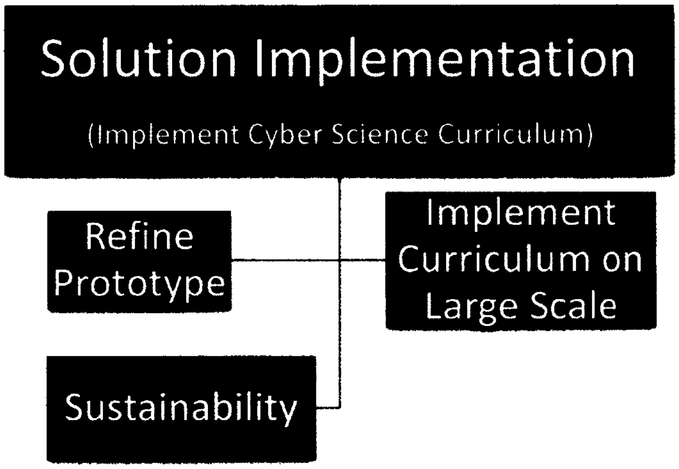

Figure 5-9: Solution Implementation stage of Cyber Science curriculum design.

5.4 Integrated Engineering Curriculum

Prior to 1997, the freshman at Louisiana Tech University took an introduction to engineering course, ENGR 100. This course was separated by major and gave the new freshman a simple overview of their specific major. Dr. James Nelson, Dean of Undergraduate Studies, was tasked with instructing the ENGR 100 section for undecided majors. It was during this time that Dr. Nelson began taking a different approach to instructing ENGR 100 students. In the past for the undecided section various instructors would come in and "teach" the class for a week giving overviews of their specific discipline. When Dr. Nelson began instructing the course, he abandoned the idea of simply providing overviews of the different disciplines, and instead approached the class with the intent to have more creative problem solving. Through the success of such a class, the need for a redesign of the freshman curriculum was evident. Thus in 1997 a redesigned freshman curriculum called the Integrated Engineering Curriculum (IEC) was established. The following description of the design behind the IEC is written from an interview conducted with Dr. Nelson, the lead on the IEC design project.

5.4.1 Problem Formulation

Key people in the College of Engineering and Science from varying disciplines, math, engineering, physics, and chemistry, were chosen to be on the team for this freshman curriculum redesign initiative. To begin the problem formulation, the design team had many discussions trying to decide the scope of the project and exactly what they wanted from the redesign. During this time there were some NSF coalitions at different institutions aimed at improving freshman curriculum. The design team invited key people within the coalitions to discuss their initiatives. Learning about the coalitions helped the design team to gain perspective on the project as well as see the elements of the coalitions they wanted to incorporate into their design. Ultimately the design team decided they wanted to create a truly integrated freshman course sequence that links the engineering, science, and mathematics courses throughout the freshman year (Figure 5-10).

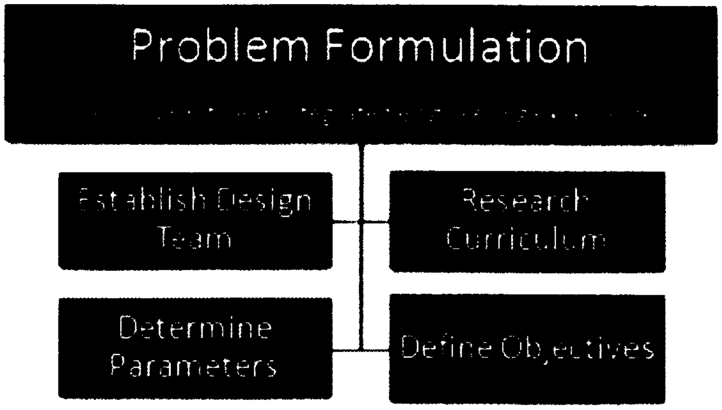

Figure 5-10: Problem Formulation stage for the Integrated Engineering Curriculum design.

5.4.2 Solution Generation

Once adequate research and discussion was conducted and the objectives of the redesign were established, the time arrived for the design team to brainstorm ideas for the curriculum (Figure 5-11). The design team worked in a room containing a large white board. They began by posting science, math, and engineering course topics using sticky notes. Through posting the topics, the design team was able to take an engineering topic and move to next to a related topic in math. The result from this process was a large grouping of potential topics for the IEC.

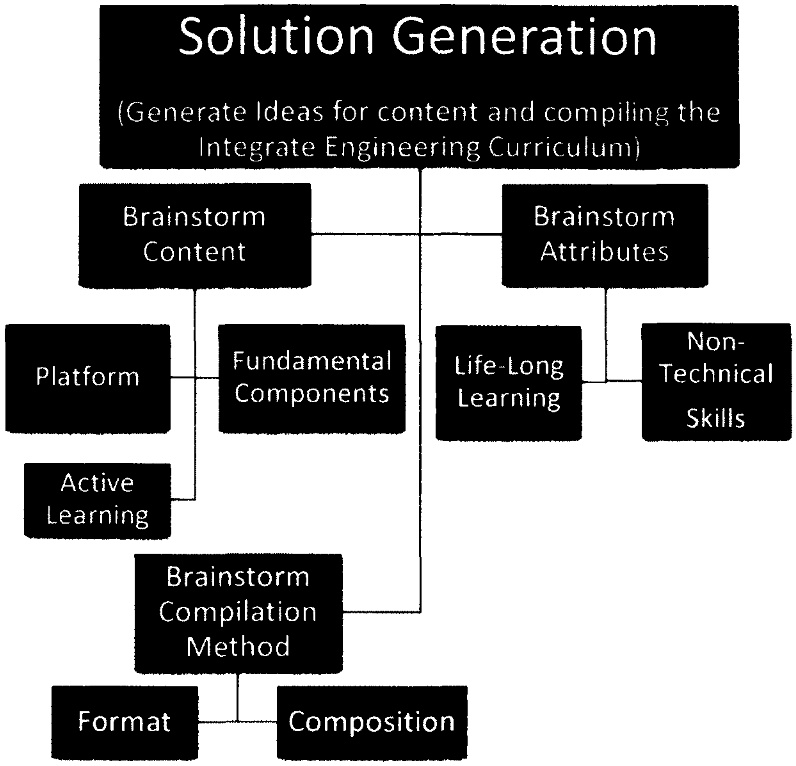

Figure 5-11: Solution Generation stage of Integrated Engineering Curriculum design.

5.4.3 Solution Analysis

Following the brainstorming sessions, it was time for the design team to analyze the different topics and groupings that came as a result of the brainstorming (Figure 5-12).

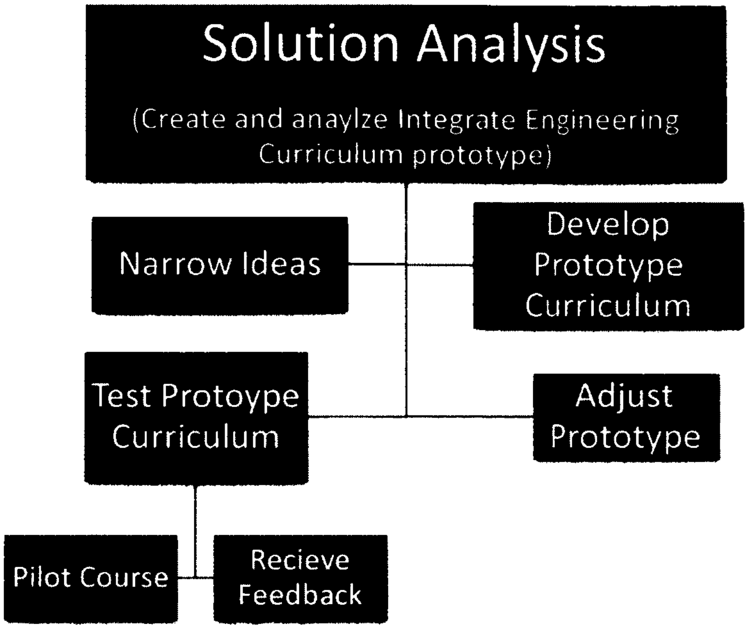

Figure 5-12: Solution Analysis stage of Integrated Engineering Curriculum design.

5.4.3.1 *Creating the Prototype*

The design team assessed the topics and developed a timeline for the courses involved in the IEC. A structure was maintained that would link certain topics in one discipline with the other disciplines the students would be taking during the same quarter. The science, math, and engineering members on the design team developed their respective course curriculum based on the decisions made on topics placement. A key component to this process was that, although the respective disciplines divided to create their own curriculum, the design team continued to meet regularly maintaining the true integration of the course as well as instilling the sense of collaboration throughout the project.

5.4.3.2 *The Prototype*

The resulting prototype was an integrated course sequence for freshman engineering students that transpired throughout the entirety of the freshman year. The math, engineering, and science topics were linked in a way that would yield deeper understanding of the topics. In addition, the engineering course sequence was based on creative problem solving and included fundamental topics such as mass balance and regression analysis rather than a simple overview of specific engineering disciplines. The curriculum prototype was intended to provide an integrated multi-disciplinary approach to the freshman year; thus, students would no longer be divided by discipline. Students would, however, be linked in the same courses together throughout the quarter; they would be in the same math, science, and engineering courses throughout the quarter. This not only helped the students build a sense of community, it allowed for the instructors of the courses to meet and discuss specific incidences throughout the quarter.

5.4.3.3 *Testing the Prototype*

To test the prototype the design team sent out letters based on ACT scores inviting the students to fill out an application to participate in the new IEC. From the applications 40 students were chosen to participate in the first pilot of the new IEC in the fall of 1997. Members of the design team taught the various courses, math, science, and engineering. Throughout the initial pilot, Dr. Nelson worked closely with the students. He held what was called "fireside chats." This gave the students an opportunity to express their concerns as well as provide feedback to the design team. Following the initial pilot phase, Louisiana Tech University received a grant from NSF to fund the IEC. After receiving funding the IEC was piloted once again; this time it expanded to two sections of students in the fall of 1998. Throughout the pilot phase the design team met extensively, discussing the pros and cons of the prototype.

5.4.4 Solution Implementation

After the pilot phase the design team worked to refine the prototype. Because of the available funding and the success of the curriculum, the design team decided it was time to have a large scale implementation (Figure 5-13). This required more faculty buy-in as well as administratively linking all the courses for the freshman sequence. To acclimate faculty with the material, workshops were held to familiarize them with the curriculum. Because the courses were blocked together, the blocked engineering, math, and science instructors would have the same students throughout the quarter. This allowed for a level of collaboration not seen before. The blocked instructors held regular meetings; thus, providing a level of communication throughout the quarter. The instructors were able to discuss topics in the course. This helped the engineering instructor know topics covered in the math and science class. Engineering instructors could make appropriate connections with their students, and the same for the math and science instructors.

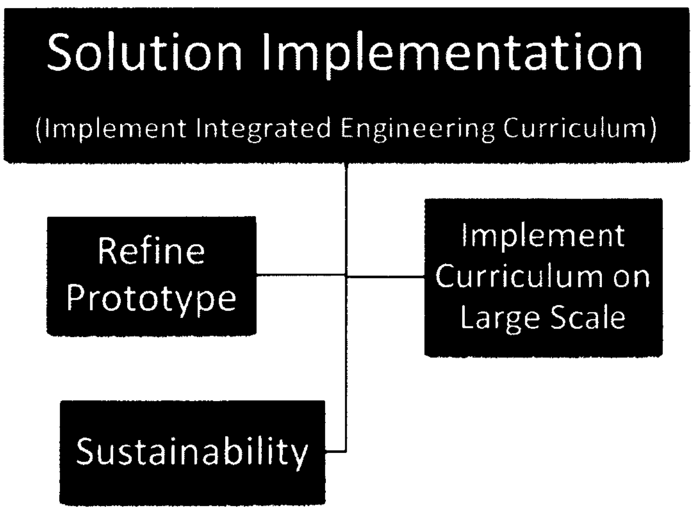

Figure 5-13: Solution Implementation stage of Integrated Engineering Curriculum design.

Throughout the implementation of the IEC, surveys were given regularly to the students. Feedback was constantly provided, with the intent to keep improving the curriculum. In the beginning one of the main areas consistently rated low was that students did not see the integration of topics from the math course to the science course to the engineering course. The instructors realized they never specified where the integration was happening. Once instructors began causally mentioning at certain points in the course that the students had seen this topic before in X class or will see this topic again in Y class, students began making the connection with the integration. Eventually the students made the connections without the instructors explicitly having to mention it.

5.4.5 IEC Success and Future Direction

The level of collaboration throughout IEC design process was unprecedented. Because of the trust and collaboration within the various disciplines the freshman curriculum was redesigned providing a true integration of disciplines. During the time of the IEC development, great strides were also made in the restructuring of the college administration. The College of Engineering was absorbing some of the science disciplines found within other colleges in the university. The college was renamed the College of Engineering and Science and a new administrative structure was proposed [67]. Each discipline within the college would have an academic director. The director did not necessarily come from that discipline, but that person would represent the discipline in the leadership team meetings. The leadership team would deal with budgetary issues and administrative type issues. Having a math person as director for an engineering discipline provided understanding of the different discipline. It yielded an atmosphere where the math person would talk to the engineering personnel and vice versa. In most universities, there are divisions amongst each discipline. The new structure encourages talking to one another instead of about one another; thus, fostering an atmosphere for more collaboration. In addition to the academic directors, each discipline has a program chair responsible for more academic decisions such as meeting ABET standards. This helps the program chair to focus on the quality of the program and not be concerned with budgetary decisions. The program chair reports to their academic director on needs for the discipline. The academic directors then present their case to the leadership team. The result, for example, is a math faculty fighting for the needs of the civil engineering faculty – true collaboration [67]. Figure 5-14 is a map illustrating the administrative structure for the College of Engineering and Science. The fact that the college initiated a change in environment and thinking by restructuring administratively yielded the opportunity for the IEC to be successful. The administrative restructuring provided institutionalized change. Without the institutionalized change, the IEC curriculum would not have been sustainable and then needed level of collaboration would not have been achieved.

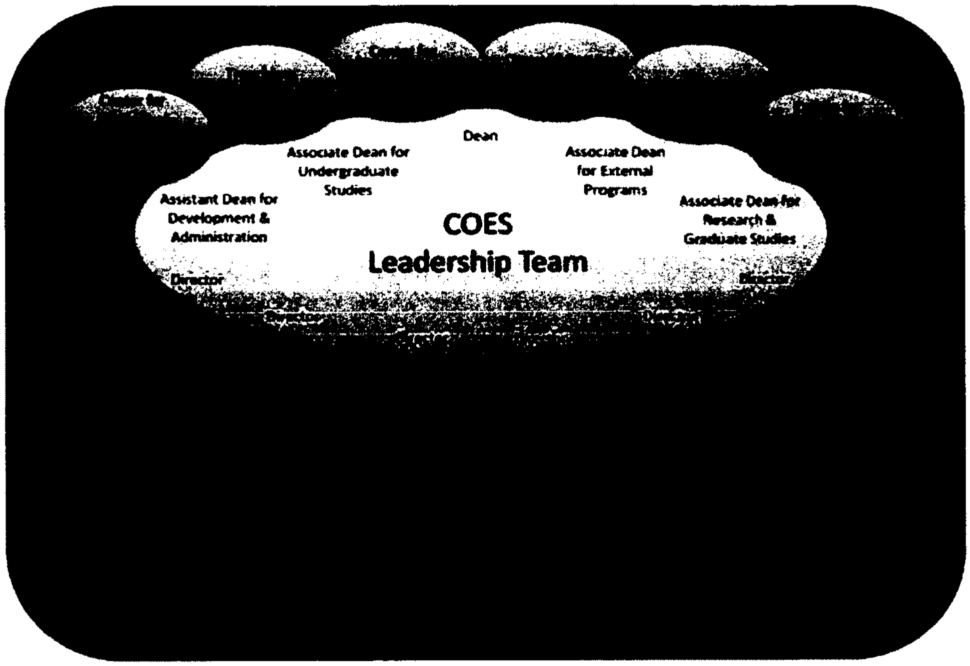

Figure 5-14: Illustration of the administrative structure for the College of Engineering and Science [67].

However, as mentioned in the framework curriculum design is never truly finished. In the early 2000s it was clear that a new iteration of the IEC design was needed. Dr. David Hall assumed the task as lead to redesign the engineering portion of the freshman curriculum. The resulting design is the aforementioned *Living with the Lab* curriculum.

5.5 Penn State University ME Curriculum

Engineering Educators at Penn State University were tasked with redesigning the Mechanical Engineering curriculum to incorporate more active learning components. The ME faculty desired a formal, structured process to approach such a large scale design problem. Being engineers, the design team naturally looked towards the engineering design process to provide such a structure. The faculty identified eight steps in the engineering design process to guide their redesign: Identify Need, Define Problem, Generate Alternative Solutions, Analyze and Feedback, Winnow (a method of purging the erroneous components), Detailed Design, Test and Refine, and Implement [63]. Although the engineering design process used by the Penn State design team is not the exact same as the one discussed in this dissertation, it can be categorized to fit into the same process. It was discussed earlier that the design process is written in different ways, but can be generalized into the four stages: Problem Formulation, Solution Generation, Solution Analysis, and Solution Implementation. Identify Need, Define Problem are sub steps in the Problem Formulation phase. Generate Alternative Solutions is the same as the Solution Generation phase. Analyze and Feedback, Winnow, Detailed Design, Test and Refine all fall within the Solution analysis phase, and finally the Solution implementation phase is parallel to Penn State's Implement step.

5.5.1 Problem Formulation

The ME faculty assessed the need of redesigning the curriculum (Figure 5-15). The faculty noticed positive results from providing active learning components in engineering courses from both experimental classes at their university as well as case studies found in research. Thus the need for the redesign was identified: to develop courses with more active learning components in a cost effective manner [63].

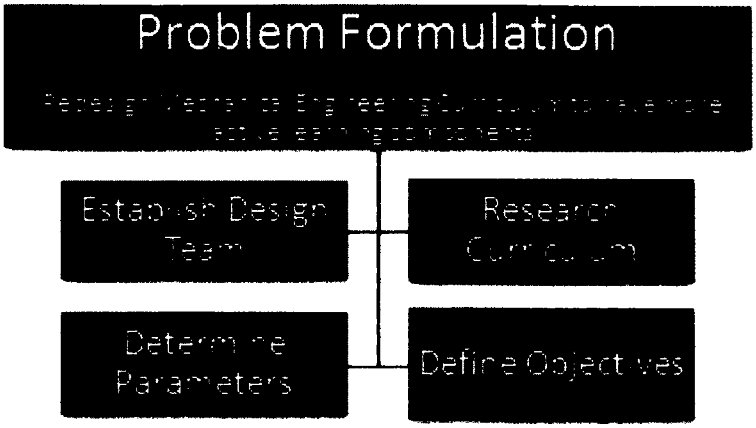

Figure 5-15: Problem Formulation stage of ME curriculum design at Penn State.

Next the faculty spent some time clearly defining the problem. The faculty gathered information about the present status of the ME curriculum by looking at student performance as well as discussions with industry personnel, students, faculty, and alumni. Through the assessment techniques, the faculty clearly defined the objectives of the curriculum redesign. The objectives were divided into two categories: Improve Delivery and Enhance Content. Then, the faculty developed an action plan to ensure the curriculum design process moved forward. At each ME meeting the curriculum design project was discussed to keep all faculty informed on the design process. The design team was officially established with the Professor-in-Charge of Undergraduate Program in Mechanical and Nuclear Engineering and the ME Department head serving as the lead overseers for the project. The remaining ME faculty were divided into sub groups to review the individual courses' content. The sub groups evaluated the content based on ABET standards. They were tasked with determining whether the content was in the curriculum, if the content was adequately covered in the course, and if the content needs improving [63].

5.5.2 Solution Generation

Once analysis of the individual courses was completed by the sub groups, the main design team moved into generating alternative solutions for the courses (Figure 5-16). The team benchmarked other nationally recognized successful ME programs. Three benchmarks were identified as potential course layouts. The first structure for the courses followed the current Penn State Model where students spend freshman, sophomore, and junior year strictly in lecture classes learning theory, and in the senior year, the students take hands-on laboratory classes. The second model established by the design team incorporates the lecture and lab into one course. The final model considered by the design team couples courses lecturing the theory with a hands-on activities clinic [63].

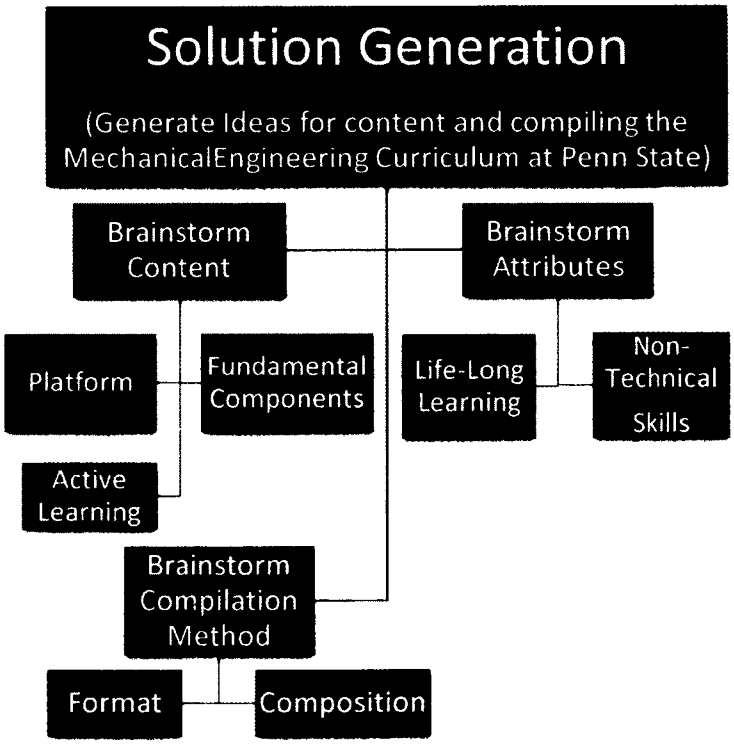

Figure 5-16: Solution Generation stage of ME curriculum design at Penn State.

5.5.3 Solution Analysis

The design team brought the alternative solution ideas to the ME faculty for further discussion, analysis, and feedback (Figure 5-17). Various design team members presented the proposed solutions for courses via presentations at faculty meetings, workshops, and a retreat. The design team also sought input on the solution ideas from current students, alumni, and the industry advisory board. Eventually the design team narrowed the solution to the third model developed. The team identified the need for a junior level design course that will maintain a heavy emphasis on theory, but will also be coupled with a clinic providing the desired active learning components. The design team worked to develop the course's detailed design. Once the detailed design was completed the course was analyzed, tested, and refined during the pilot phase. Initially the course was piloted with one section in the spring term. Then, it was once again piloted with two more section in the fall term [63].

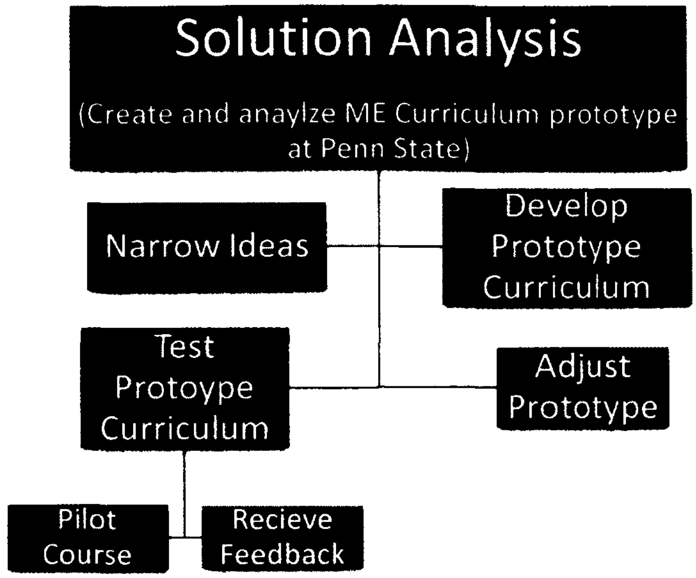

Figure 5-17: Solution Analysis stage of ME curriculum design at Penn State.

5.5.4 Solution Implementation

Following the pilot phase the design was refined and ready for full implementation at the university (Figure 5-18). Due to the success of using the engineering design process to redesign the ME curriculum, Penn State's engineering department, now uses the process as a standard for curriculum redesign. Any curriculum redesigns must adhere to the process.

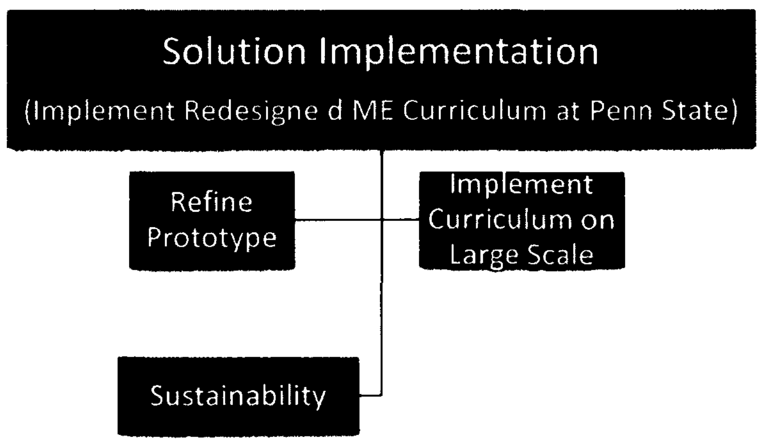

Figure 5-18: Solution Implementation stage of ME curriculum design at Penn St.

5.6 Brigham Young University-Idaho Capstone Course

In the 2001 Rick's college, a two year institution, became Brigham Young University-Idaho (BYU-Idaho). Now a four year university, the school was tasked with developing the course curriculum for the additional two years of instruction. The university developed an adequate capstone course for the engineering seniors. However, when Dr. Alan Dutson joined the faculty in 2003, he was tasked with developing a better capstone design course. Since the course itself is about design and he was approaching a design problem, it seemed fitting to use the engineering design process to provide structure in designing the course curriculum [62].

5.6.1 Problem Formulation

Initially, Dutson worked to clearly define the problem (Figure 5-19). He identified the customer needs. Dutson took the point of view for each customer associated with the course: students, industry, the department, and ABET. Metrics were established using a metrics matrix. In the metrics matrix were topics such as: teamwork skills, written communication skills, oral communication skills, design methodology, CAE skills, manufacturing skills, course duration, project sponsor, appropriate number of student hours per week, and many others. He used the matrix to cross these metrics with needs such as: provide marketable skills, significant design experience, appropriate effort, produce a quality product, meet department objectives, among others.

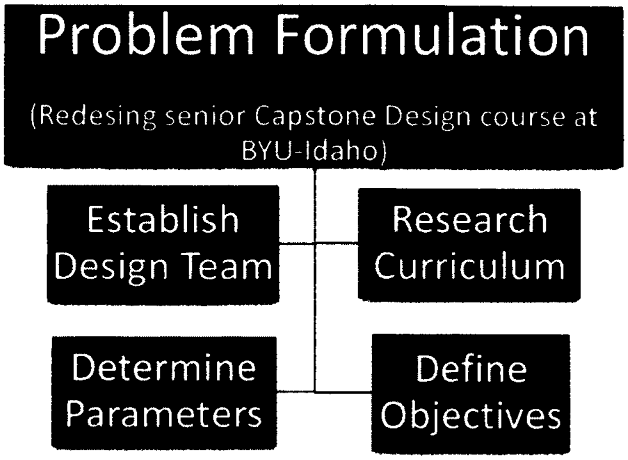

Figure 5-19: Problem Formulation stage of Capstone curriculum design at BYU-Idaho.

5.6.2 Solution Generation

After evaluating the metrics matrix, Dutson began generating solution ideas (Figure 5-20). He brainstormed several course concepts for the different design variables. Table 5-2 shows the various design alternatives Dutson generated. He used the design concepts to develop three product concepts alternatives for the curriculum of the course, shown in Table 5-3.

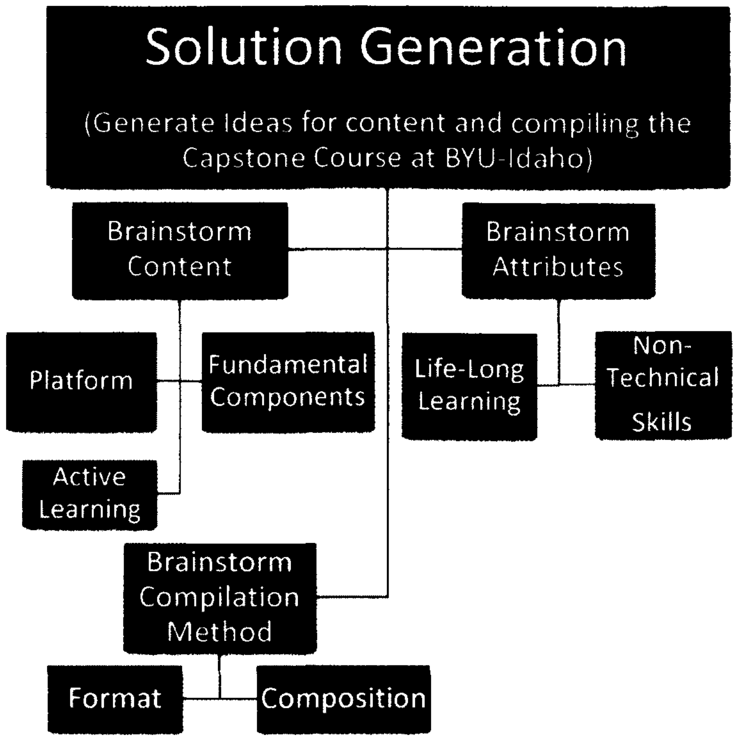

Figure 5-20: Solution Generation stage of Capstone curriculum design at BYU-Idaho.

Table 5-2: Dutson's design concept alternatives [62].

Design Variables	Design Concept 1	Design Concept 2	Design Concept 3	Design Concept 4
Course duration	1 semester	2 semester	3 semester	4 semester
Project sponsor	Industry	Department	Student	Non-profit
Required deliverables	Paper design w/ detail drawings	Prototype	Production Sample	
Number of faculty involved	1-2	25 %	50 %	100 %
Role of faculty	Consulant (Infrequent contact)	Coach (weekly contact)	Instructor (multiple contacts per week)	
Course structure / sequence	1-semester project	1-semester design course + 1-semester project	2-semester project (back to back semesters)	1-semester design course + 2-semester project
Project cost	< $500	$500 - $3,000	$3,000 - $10,000	> $10,000

Table 5-3: Product concept alternatives developed by Dutson [62].

Design Variables	Product Concept A (Keep it Simple)	Product Concept B (Middle of Road)	Product Concept C (Heavy Duty)
Course duration	1 semester	1 or 2 semesters	2 or 3 semesters
Project sponsor	Student or Department	Department, Industry, or Non-Profit	Industry
Required deliverables	Paper design w/ detail drawings	Prototype	Production Sample
Number of faculty involved	1-2	50%	100%
Role of faculty	Consulant (Infrequent contact)	(1-2 as instructors, others as consultants)	(1-2 as instructors, others as coaches)
Course structure / sequence	1-semester project	1-semester design course + 1-semester project	1-semester design course + 2-semester project
Project cost	< $500	$500 - $3,000	> $10,000

5.6.3 Solution Analysis

Following the generation phase, Dutson began analyzing the product concept alternatives (Figure 5-21). Keeping with the engineering design process, Dutson used a scoring matrix to analyze the solution ideas, knowing that the highest scoring alternative would yield the optimum solution. It was determined that the Product Concept B would provide the best results. Thus, Dutson had adequate information to show the engineering faculty and begin developing the prototype. Through the iterative nature of the design process the course prototype eventually became a hybrid of Product Concept B and C [62].

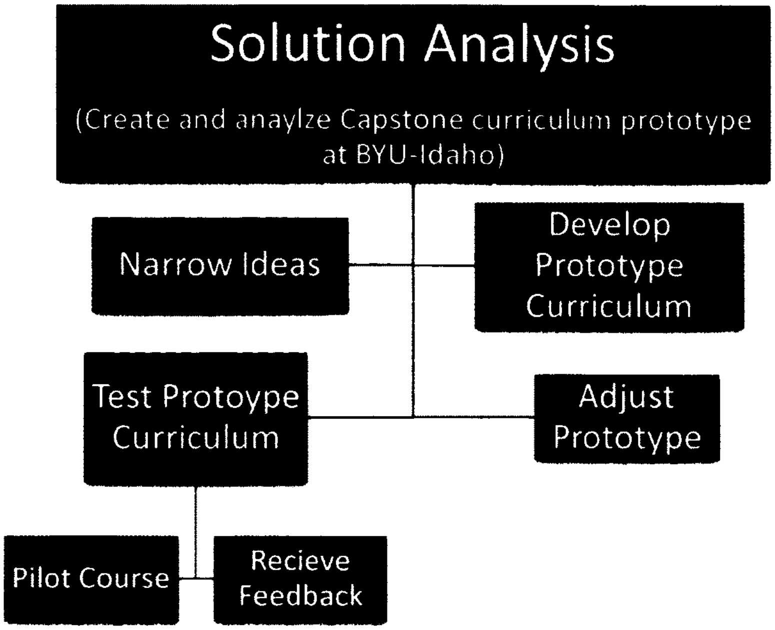

Figure 5-21: Solution Analysis stage of curriculum design at BYU-Idaho.

5.6.4 Solution Implementation

After Dutson's analysis of the curriculum, BYU-Idaho was able to implement a more rigorous course program that suits the needs of the institution and those associated with it (i.e. students, faculty, and industry) (Figure 5-22). The curriculum is a three course program. The first course emphasizes design methodology. The second course houses the capstone project, and the third course, offered optionally, is for students' whose project requires more time for completion.

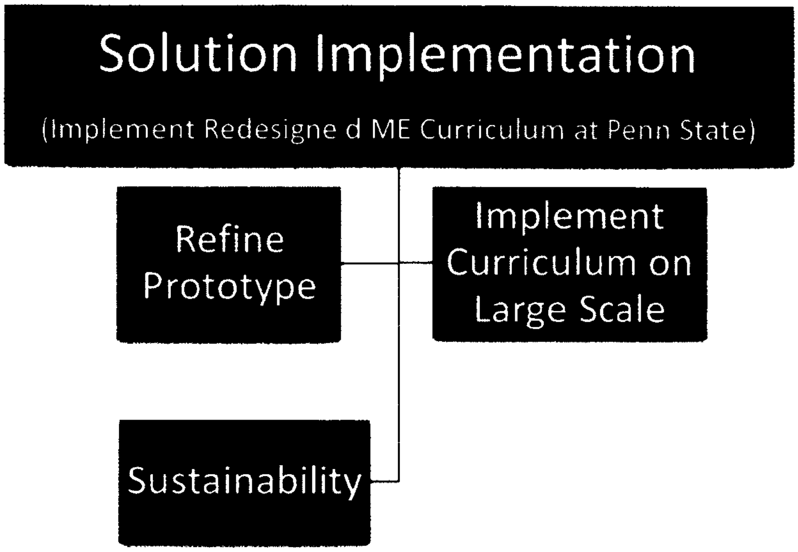

Figure 5-22: Solution Implementation stage of ME curriculum design at Penn State.

5.7 Deviation from the Framework

It is important not to deviate from the framework when designing a curriculum. There are instances where deviation from the framework has resulted in clear pitfalls in the design. Specifically, in the Integrated Engineering Curriculum, the design team aligned themselves with the framework throughout much of the design process. However, in the final stage, the design team started to deviate from the sustainability sub-step. In the beginning of the implementation phase, collaboration and communication was major component of the IEC's sustainability. As time progressed the communication lessened, thus resulting in a breakdown of the true integrative nature of the curriculum. However, because of the breakdown, it was evident to those involved with the curriculum that the next iteration of design should be conducted.

When the Cyber Science course deviated from the framework in the Solution Analysis phase, the curriculum development process became stagnant. As the Cyber

Science design team divided sections of the curriculum to be developed into the prototype communication among members ceased. Members of the team were writing content at varying levels resulting in a disjointed curriculum. Because of external influences, the design team pushed forward to the piloting phase where adequate feedback was not obtained from instructors teaching the material. Due to the deviation from the framework, the design team had to refer back to the Problem Formulation phase to assess the addition of new design team members to aid in further developing the curriculum, leading to more iterations of the prototype development sub-step in the Solution Analysis phase.

Understanding the pitfalls exposed by these curricula when deviations from the framework occurred emphasizes the importance of remaining on task with the framework. Any deviation can result in major revisions to the curriculum. Additionally, when deviations do happen, identifying where the deviation occurred should aid in knowing how to get back on task. In the IEC, the deviation occurred in the sustainability of the curriculum years after it had been implemented, thus, leading to the next iteration of the course. In the Cyber Science curriculum the deviation occurred in the Solution Analysis phase causing the team to look back at the Problem Formulation phase.

CHAPTER 6

CONCLUSIONS AND FUTURE WORK

6.1 Conclusions

As the National Research Council for psychology identified, learning fundamentals, not overly contextualizing, creating an environment of excitement, and recognize that new concepts build on old concepts all promote learning for transfer [5]. Motivated STEM educators want their students to have a deep understanding of STEM concepts. They have taken strides to understand what is needed to make changes in the classroom so that they encourage learning for transfer amongst their students [6-8]. Many have taken the steps from simply understanding what needs to be done and, in response, have created programs that foster the qualities needed to learn for transfer. Continuation of this trend is necessary for the STEM community so that future students received the best opportunity for learning in STEM classrooms.

Many STEM educators strive to improve the quality of the curriculum that is presented to the students. Ultimately engineering educators want to teach curriculum that provides a deep level of understanding and learning for transfer by the students in the course. Engaging students in the classroom has been shown to provide this level of understanding. STEM educators must understand how to best employ the engaging techniques in the curriculum such that the fundamentals are not lost in the projects. A framework for curriculum design is essential to understand how best to incorporate these engaging pedagogies. Since the process of integrating new projects and technologies into the classroom requires design, STEM educators can turn to the engineering design process in order to accomplish the task of curriculum design. The validity of using such a process for curriculum design is rooted in the fact that the engineering design process has been used for many years. It is the standard design process taught to engineering students as well as a standard in industrial design.

This dissertation outlined a framework for curriculum design based on the principles of the engineering design process. STEM educators can use the framework as a structure to base curriculum design. Successful STEM curriculum designs using such a framework were discussed: NASA-Threads, Cyber Science, Penn State M.E. curriculum, and BYU-Idaho Capstone course. It is necessary to note that curriculum design is a humanistic process. Many of the decisions made during the curriculum design process are not black and white, but rather must be approached carefully due to the various people involved in the design (i.e., instructors, students, administrators, etc.). Additionally, the framework for the design process is just that, a framework. STEM educators should use the framework and adapt it to their environment. A major point in the framework that should be utilized, regardless of the institutional culture, is the iterative nature of the framework. Curriculum design is a fluid process. It is ever changing to the container that holds it; thus, the curriculum

> **"Developing curricula [illegible] patience. It also takes the [illegible] compromise. There were times [illegible] wanted a certain activity in a lesson [illegible] just didn't fit. I had to learn to let it go [illegible] keep it in my toolbox for later. With the new common core standards that are due to come out soon, engineering is a big part of [illegible] We will need engineering educators to [illegible] make effective lessons that relate to [illegible]."**
>
> **-Missy Wooley**
> **K-12 STEM Educator**

process is never finished. There are always improvements that can be made whether new technology should be used, or projects should be adapted to changes in social perspectives, and so on.

6.1.1 Summary of Framework

The curriculum design framework discussed in this paper consists of four main aspects which are rooted in the engineering design process: Problem Formulation, Solution Generation, Solution Analysis, and Solution Implementation. Each of the four main phases consists of sub-steps that help to create an improved STEM curriculum. An overarching theme associated with the framework is the iterative nature of the process. The design team should keep in mind that iteration is the key to creating a refined product and should not be discouraged when at the Solution Analysis phase a look back at the Problem Formulation phases is needed. Additionally, the design team should keep in mind that the curriculum design can be lengthy; thus, adequate time must be allotted for the design process.

When beginning the Problem Formulation phase, the first step is to establish the design team. To create a solid STEM curriculum, the responsibilities of design should not fall on one person alone. Instead, a diverse team of individuals should be established that would provide varying perspective to the design. The team should consist of individuals willing to work together and collaborate throughout the process. True collaboration is essential in achieving the best design solution. Once the design team is established, the next step is to research curricula associated with the curriculum being designed. In this step the design team should look at similar curricula to what they are designing. This could provide the design team with a baseline for their design. If the curriculum is a redesign, the team should look at the current state of the curriculum being offered. Talking to experts in the field can also be beneficial at this stage in the design process. The design team should talk to instructors teaching the current curriculum or if the curriculum is completely new, the design team can talk to instructors teaching related topics. This stage provides the team with a well-rounded understanding of the curriculum, which leads them into defining the objectives of the design. Prior to completely defining the objectives of the curriculum design, the design team should assess the various parameters associated with the curriculum design. The parameters the design team should look at include level of instruction (K-12 versus College), time allotted for course, budgetary influences, etc. Once parameters are established, the design team should clearly define the objectives of the design. Objectives the design team should establish are pedagogy associated with curriculum (PBL, platform, inquiry), depth of material developed (lesson plans, master notes, tests, homework), etc.

Following the Problem Formulation phase, the design team moves on to the Solution Generation phase. This phase consists of three components: Content, Attributes, and Compilation. The design team should brainstorm the content in the curriculum, non-technical attributes, as well as the method of compiling the curriculum content. When brainstorming the content two aspects are addressed: fundamentals and active learning components. The fundamentals are the core of a STEM course. The design team should brainstorm the fundamentals associated with the curriculum then brainstorm the various active learning components and non-technical components that can be associated with the given fundamentals. At this stage, the design team may develop numerous active learning components for the various fundamentals. This is okay; the more ideas the better. Later in the Solution Analysis phase the design team will narrow down the ideas. Additionally in the Solution Generation phase, the design team should brainstorm ideas on how to compile the material. Compiling ideas should include format of curriculum as well as method of presenting materials (website, hard copies).

After adequate brainstorming time, the design team moves into the Solution Analysis phase. This phase consists of narrowing down the ideas developed in the Solution Generation phase. When narrowing the ideas of the fundamentals with active learning components the timeline associated with the curriculum begins to develop which lends itself to the design team beginning to develop the prototype curriculum. At this stage the design team may want to divide and conquer the actual lesson development. Once the prototyped is developed to the level identified in the Problem Formulation phase, the design team should test the prototype. Testing prototype curriculum is conducted by piloting the course in a control group consisting of instructors involved in the design or instructors that will maintain active feedback to the design team. Throughout the pilot phase, the design team should work to improve the prototype given the various feedback from the piloting instructors.

Following Solution Analysis phase, the design process moves into the Solution Implementation Phase. At this point in the design process, the design team should refine the prototype to a more finalized design. Then the team implements the curriculum on a larger scale than the pilot group. The design team should work to make the instructors of the curriculum comfortable with the material. This can be done in a variety of ways such as workshops, seminars, mentoring programs, etc. Also the design team should address issues associated with the sustainability of the curriculum. To emphasize this summary Figure 4-2 is duplicated for the reader as Figure 6-1.

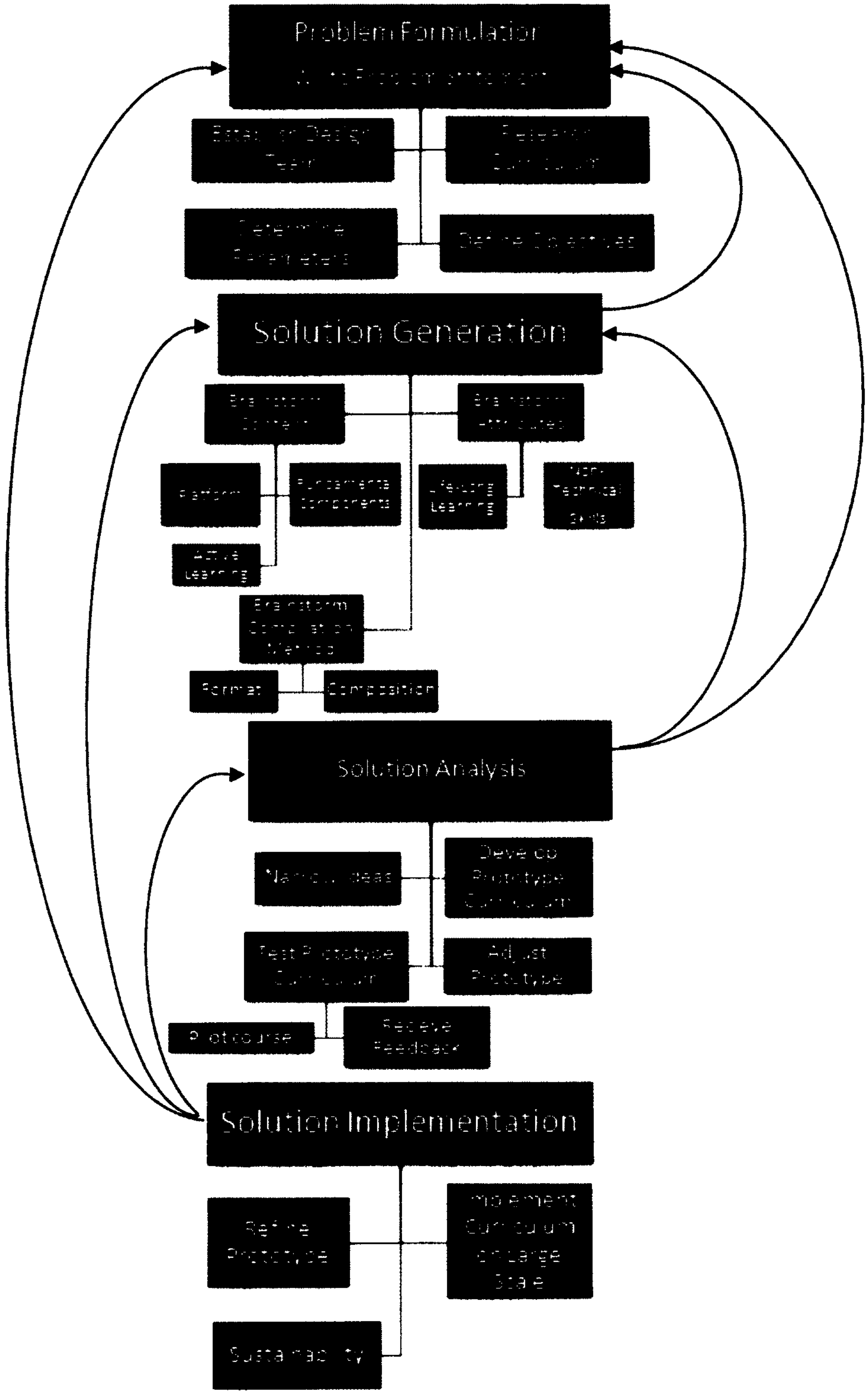

Figure 6-1: A pictorial representation of the curriculum design framework.

6.2 Future Work

Identifying and developing this curriculum design framework yields many opportunities for future work. Obviously, the ability to apply the framework to various STEM courses on the collegiate and K-12 level is endless. By outlining the framework, many others could utilize the process to design/redesign curriculum. Specifically, the *Living with the Lab* curriculum was created as a continued iteration of development of the IEC which was initially implemented 15 years ago. It has now been 8 years since the iteration resulting in the design of the *Living with the Lab* curriculum; thus, it is time for the next iteration of the freshman curriculum. Utilizing the framework established in this dissertation would be a beneficial structure to the next iteration of the freshman curriculum design.

Penn State has used the engineering design process to analyze and develop curriculum on a large scale. Penn State took the design process to evaluate and redesign the mechanical engineering curriculum. The majority of this dissertation focused on curriculum design on a course basis. Future work could be applied to refine the design process as it relates to larger scale design similar to what Penn State has done. At Louisiana Tech University, the freshman curriculum has been a major focus for curriculum design, but there is a need to expand into the sophomore and junior years. Looking at large scale multi-course curriculum design for this scenario, a structured process like the framework described in this dissertation can be utilized. In addition to using the framework to design/redesign certain curriculum, there is potential to write an instructional book outlining the framework in more detail such that any STEM curriculum developer, whether trained in the engineering design process or not, could pick up and use as a guide for designing curriculum.

Another future research direction related to the framework is to develop a more precise validation instrument that measures the success of the framework. The current validity of the framework is rooted in the fact that it is based on the widely accepted engineering design process. The design process has been tested and proved as an effect process for design. However, relating the engineering design process to curriculum design is a relatively new concept. Thus, for future work, research should be conducted to develop a validation instrument. Currently, research shows the success of a STEM course as it relates to the pedagogies used in the course. Students are shown to gain a greater understanding of the material. These results however, do not directly identify that the development process of the curriculum is a direct relation to the better understanding, but rather the engaging pedagogies are attributed to the better understanding.

APPENDIX A

SURVEY

An informal survey was given to various faculty at Louisiana Tech University involved in STEM curriculum design initiatives. Additionally the survey was given to two key high school instructors heavily involved in STEM curriculum design at Louisiana Tech University. Table A-1 is a compilation of the survey results from all respondents.

Table A-1: Compilation of the survey results on writing STEM curriculum answered by Louisiana Tech University faculty and high school instructors.

Question 1 – What curriculum have you helped develop and what was your role in developing the curriculum?	
D. Hall, PhD	Living with the Lab – Lead developer; manager of content, NASA Threads – Developed half of the "work and mechanics" content, I have developed a number of other courses that include applications, Led the development of original "sophomore" integrated curriculum (220, 221, 222), Led or had major involvement in two or three MEEN curriculum re-designs.
K. Crittenden, PhD	Living with the lab – minimal role in curriculum development, helped more with the testing and implementation; TechSTEP – helped conceive, test, and deliver most of this curriculum; IMPaCT – created this curriculum; CyberDiscovery – developed the "engineering" part of this curriculum, modified from LWTL; NASAThreads – helped create a few of the lessons; FrEP - Co-Created the engineering class that goes with the Math.
D. Harbour, PhD	I helped develop parts of LWTL and NASA Threads.
M. Barker, PhD	David and I worked together closely at the beginning of the LWTL. We equally shared trying to generate a project (the fishtank project) that would relate to the topics we selected for the 1st quarter (circuits and mass). So I would say that our role was to select/identify the content area or subject matter, then decide the level of coverage (appropriate for freshman with their math skills).
T. Atkison, PhD	Cyber Science - Developed one third of the computer science lessons; Cyber Discovery 2.0 - Developing the technology portion to include the technology lecture/demonstrations/in-camp participation; Also developing the technology aspects of the camp-long investigative scenario.
J. Gourd, PhD	I've dabbled in a number of areas, but mostly it has been with Cyber Engineering. Mainly, I submitted a white paper (pre-proposal) for a pilot in Cyber Engineering several years ago to the DHS.
J. Mhire, PhD	Cyber-Discovery 1.0; Cyber-Discovery 2.0; Cyber-Science. Role = LBAR

M. Wooley	developing the curriculum? I helped develop the RIPPLE curriculum that Louisiana Tech University uses to train middle & high school physics teachers. I also helped write the STEM curriculum at Ruston High School.
M. Nelson	I helped develop the NASA-Threads Physics curriculum, working with Louisiana Tech COES. I reviewed the overarching structure and content of the curriculum, provided feedback on modules as they were developed, helped draft two units (Waves & Sound, and Light), and piloted the curriculum at Benton High School.I have also taken activities/curricula from the TechSTEP and Cyber Discovery Camp programs (and/or content modeled on these activities) back to my school and incorporated them into math lessons in Algebra 1, Geometry, and Advanced Math.
Question 2 - How was the content of the curriculum determined?	
D. Hall, PhD	Start with the intent to bringing in interesting applications; See what hardware and software is available to support applications; Adopt a "platform"; Think about what fundamentals to be taught; Brainstorm on ways that the "platform" can be used to support fundamentals; Implement applications and larger projects to make sure everything works; Nail down the content.
K. Crittenden, PhD	Team brainstorming; Some curricula had state/ABET standards that we were trying to meet.
D. Harbour, PhD	For the parts I was involved in, we decided on the curriculum in a small committee setting.
M. Barker, PhD	My recollection is that we didn't stray too far from the already established content for the Integrated Engineering curriculum. That content was introductory in nature, and selected to link with math concepts.
T. Atkison, PhD	Cyber Science - A team of three computer science faculty worked together to outline a path of action that would provide a breadth of computer science knowledge for the student. This was vetted through the entire cyber science team to insure that overarching goals were accomplished and themes were consistent. Cyber Discovery 2.0 - The core team discussed high level ideas/themes for the camp and the technology team developed the technology content.
J. Gourd, PhD	Mostly with input from Dr. Kamal Jabbour at the AFRL in Rome, NY. From there, internal discussions with key faculty members in EE, CS, Engineering, and others (e.g., Galen Turner).
J. Mhire, PhD	in each instance jointly, either between myself and Etheridge, or myself and Turner.
M. Wooley	We used the 5E learning cycle and either pulled lessons from curriculum CATALyST (a program at Tech) had developed, lessons from the Exploratorium in San Francisco or I developed them.
M. Nelson	Tech faculty developed a course outline based on content needed for success in college physics, engineering, and other STEM degree programs. We also reviewed the Louisiana DOE Grade Level Expectations (GLEs) and Comprehensive Curriculum, along with other standards, including College Board AP Physics Course requirements, to generate a comprehensive outline of the content needed to both meet state requirements and fully prepare students for STEM degree programs.

[illegible]	
D. Hall, PhD	This boils down to having qualified people designing the content.
K. Crittenden, PhD	Most of this curriculum was piloted on a small scale first.; The curricula that I taught myself did not have a strong "written down" component. Curricula that were made to be taught by others have undergone multiple iterations.
D. Harbour, PhD	For LWTL, the university faculty met during summer sessions to review that material and work through the labs and projects. For NASA Threads, we presented our early results to the high school faculty who would be using it to get their feedback.
M. Barker, PhD	Internal quality control by the two people working on the curriculum for maybe 1 or 2 years. Then Mikey came on board, and Kelly I think, and more fabrication added as well as depth of knowledge about the behavior in the fishtank, including soliciting a chem expert (Eddy) to help understand the water and what we needed to do about it.
T. Atkison, PhD	Cyber Science - Each module was passed between the three team members and each writer assured that their technical path was accurate. Sometimes it didn't work out as we hoped. Cyber Discovery 2.0 - Each activity that will be used either in the camp lecture meeting or during the weeklong experience is or will be completed by the technology team to make sure of its accuracy.
J. Gourd, PhD	No "formal" measures, but let's say that discussions with a variety of faculty, staff, and administrative folks assisted in vetting the curriculum. And it is still actively being tweaked.
J. Mhire, PhD	mostly it was expert feedback.
M. Wooley	We used inquiry based lessons and used research based strategies as a guideline.
M. Nelson	Tech faculty members established guidelines for quality (content, format, review process…) at the onset. Tech faculty members worked with high school teachers to vet all materials generated for the course. A third party was also brought in to review the material as I recall (but I do not recall who filled this roll).
Question 4 - Was there a piloting phase with the curriculum? If so, what lessons were learned during the pilot?	
D. Hall, PhD	Kinks are worked out with pilot groups; Projects are revised; Course materials are improved (drop some things, add others).
K. Crittenden, PhD	Yes, most all of the projects that I have been involved with included a pilot phase. One of the first lessons with TechSTEP was that the high school teachers' are much more comfortable with the curriculum if they have some type of training before they are asked to deliver the material to their students.
D. Harbour, PhD	For LWTL, there was a piloting phase with the Honors classes. For NASA Threads, I seem to recall that the first year was a pilot a just a few schools.

M. Barker, PhD	We piloted using the honors for a couple of years, but only in 121 and 122. Then piloted a couple more years 120-122 still in honors. Fundamental content didn't change much. Understanding of the behavior of the project grew/improved. Also info about the workload that the students could handle and the content level they could understand.
T. Atkison, PhD	Cyber Science - Yes, there are too many to list here. Structure/length/order were the main outcomes of the pilot. Through the pilot we were able to determine in many cases what we as faculty feel can be accomplished in a set amount of time is not what can be done in that environment. We received excellent feedback on ordering of topics so that the students better received them. Cyber Discovery 2.0 - Currently working on the pilot.
J. Gourd, PhD	Actually, we are piloting the introductory CS courses within the CYEN curriculum this term. Other than that, no.
J. Mhire, PhD	yes, but two are still going through it, so the jury is still out.
M. Wooley	Yes...in all curricula there was a trial year in which we were able to tweak the curricula as needed.
M. Nelson	The content was piloted at three schools and teachers provided feedback which was incorporated into the first formal release of the curriculum.
Question 5 : What measures were taken to help instructors of the curriculum become comfortable with the material?	
D. Hall, PhD	Training is necessary after the pilot phase; Pilot phase usually includes only the developers (no training may be needed); Co-teaching (as in LWTL) before taking a section independently.
K. Crittenden, PhD	TechSTEP – the teachers were presented the material 1 to 2 weeks before the students. Other curricula had training workshops during the summer.
D. Harbour, PhD	For both LWTL and NASA Threads, summer sessions were held with the faculty.
M. Barker, PhD	I'll focus on when we took LWTL mainstream: the internal workshop to familiarize faculty to teach included significant hands-on activities (same as students) but with more explanation of what we knew about the physics/behavior.
T. Atkison, PhD	In both Cyber Science and Cyber Discovery 2.0 we used teacher workshops.
J. Gourd, PhD	Travis Atkison and I are the only instructors at the moment (for the pilot). We developed the pilot and are teaching it this term. Regarding the other courses, most exist already in other programs (like CS, EE, Engineering, and so on). For the CYEN-specific courses, we will be developing those in the near future. I will be teaching many of them, and a limited other folks will also participate.
J. Mhire, PhD	workshops

M. Wooley	The instructors were in on the development stage. For teachers that we taught, we put them in the students' seats in order for them to experience what their students will experience. They had the same ideas and questions that their students will have. It is important for teachers to struggle with material from time to time to remind them where their students are coming from.
M. Nelson	Tech COES laid the groundwork for the curriculum with the TechSTEP program, which introduced area high school faculty to the collaborative, activity/project based learning process incorporated in NASA Threads. Tech faculty held a week long workshop and follow up meetings/workshops to train high school faculty. Tech faculty members (and supporting staff) also stayed in contact with high school faculty throughout the piloting process, visited high school classrooms, and provided online resources. Instructors involved in the course development, including myself, also acted as mentors and collaborated with new instructors throughout the process.
Question 6 – What was the most difficult part of developing the curriculum?	
D. Hall, PhD	Finding the time; Getting cooperation from others (administration, programs, buy-in, . . .); Getting the funding.
K. Crittenden, PhD	Getting it done ahead of time. Many times we were only slightly ahead of the students who were taking the class.
D. Harbour, PhD	For NASA Threads, the most difficult part for me was trying to determine the appropriate level for the material. In particular coming up with homework problems was difficult for me.
M. Barker, PhD	Developing/tailoring/tweaking the project to give meaningful results that students can connect to. (also TIME spent)
T. Atkison, PhD	In both Cyber Science and Cyber Discovery the most difficult part is finding new, innovative and exciting ways to relate the material to the student at an appropriate level. That being said that is the same struggle we have here at the university as well but it was more challenging for these curriculum, as we do not interact with that age group and that dynamic on the constant basis as we do with the university student.
J. Gourd, PhD	Getting it approved through the BoR.
J. Mhire, PhD	seeing the whole before making the parts.
M. Wooley	Keeping fresh ideas coming...especially at the end of the curricula. We wanted to be sure that we didn't have cookie cutter lessons that were the same over and over. It was important for us to use different strategies throughout in order for teachers and students to be exposed to different brain-based strategies and research based strategies.

M. Nelson	Developing a full course curriculum, designed to stand-alone (without a textbook), is a significant undertaking. The sheer volume of material, including master notes, graphic aids, lesson plans, activities, problems sets, quizzes, and tests was significant. Probably the biggest design challenge was to maintain a high level of hands-on, activity based learning, while covering the full physics curriculum in a single semester. This remains a challenge and, in practice, teachers have to tailor the material to fit the constraints of the semester, block, or modified block used in each school system.
[illegible]	
D. Hall, PhD	Courses should frequently come back to fundamentals (keep just a few fundamentals); The courses should be active . . . as fun as possible.
K. Crittenden, PhD	Visual; Active/hands on; Relate content back to fundamentals (CoE, CoM, . . .); Examples drawn from common experiences (don't idealize everything).
D. Harbour, PhD	In general (I hope this is meant to be a general question), I think that every STEM course should cover some type of engineering fundamentals and then use those fundamentals in solving problems. To me it is all about practice using fundamentals in problem solving.
M. Barker, PhD	Not Answered
T. Atkison, PhD	I feel that any of these curriculums must include exciting hands-on methods for learning. We need to constantly adapt and change to the environment and give the student multiple pathways for learning. Students are used to handling multiple streams of information presented at the same time, therefore we must adapt our teaching the same way to excite them. So it doesn't matter the exact content component as long as the instructor is making it relevant and exciting for the student.
J. Gourd, PhD	This is a hard question to answer. It is curriculum-specific to an extent. But core Engineering ideas, core foundational ideas in math, engineering, and relevant sciences.
J. Mhire, PhD	Not Answered
M. Wooley	First of all it needs to be rigorous. It is important to integrate math in to the science as well as bring engineering strategically into the lessons.
M. Nelson	We have incorporated all of the components developed into our curriculum. In order to accommodate the full curriculum, Benton High School has developed a two semester (STEM Physics 1 and 2) version of the NASA-Threads curriculum. Starting in 2012-2013 school year, this will be the only Physics curriculum offered in the school.
Question 8 - Any additional comments or thoughts are welcome...!	
D. Hall, PhD	None

K. Crittenden, PhD	Actually, I just thought of something. I think it will be important to find some way to quantify the success of the developed curriculum. Some type of real assessment will need to be done in order to determine if the developed curriculum has an impact on student learning.
D. Harbour, PhD	None
M. Barker, PhD	None
T. Atkison, PhD	None
J. Gourd, PhD	None
J. Mhire, PhD	None
M. Wooley	Developing curricula takes time and patience. It also takes the willingness to compromise. There were times that I really wanted a certain activity in a lesson and it just didn't fit. I had to learn to let it go and keep it in my toolbox for later. With the new common core standards that are due to come out soon, engineering is a big part of it. We will need engineering educators to help us make effective lessons that relate to specific content.
M. Nelson	Implementing this type of rich, activity-based, curriculum within our school system continues to be challenging, primarily due to the time constraints imposed by the block system (in terms of the number of contact hours in a semester/course and the GLEs /content that must be covered), staffing (adding more course options / class size) and challenges in scheduling students around other CORE 4 course requirements along with electives - including athletics and band which can fill a full one-fourth of a student's schedule over a 4 year period (one block out of four each semester).

APPENDIX B

APPROVALS

B.1 IRB Approval Letter

LOUISIANA TECH
UNIVERSITY

OFFICE OF UNIVERSITY RESEARCH

MEMORANDUM

TO: Ms. Krystal Corbett and Dr. Heath Tims

FROM: Barbara Talbot, University Research

SUBJECT: Human Use Committee Review

DATE: February 14, 2011

RE: Approved Continuation of Study HUC 679

TITLE: **"NASA –THREADS-Part of NASA Education Funded Grant"**

HUC- 679

The above referenced study has been approved as of February 14, 2012 as a continuation of the original study that received approval on February 21, 2011. **This project will need to receive a continuation review by the IRB if the project, including collecting or analyzing data, continues beyond February 14, 2013.** Any discrepancies in procedures or changes that have been made including approved changes should be noted in the review application. Projects involving NIH funds require annual education training to be documented. For more information regarding this, contact the Office of University Research.

You are requested to maintain written records of your procedures, data collected, and subjects involved. These records will need to be available upon request during the conduct of the study and retained by the university for three years after the conclusion of the study. If changes occur in recruiting of subjects, informed consent process or in your research protocol, or if unanticipated problems should arise it is the Researchers responsibility to notify the Office of Research or IRB in writing. The project should be discontinued until modifications can be reviewed and approved.

If you have any questions, please contact Dr. Mary Livingston at 257-4315.

A MEMBER OF THE UNIVERSITY OF LOUISIANA SYSTEM

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B.2 IRB Proposal

Do you plan to publish this study?	XYES ☐NO
Will this study be published by a national organization?	**XYES ☐NO**
COMMENTS: This study is part of a NASA Education funded grant that works in conjunction with Louisiana Tech and Lincoln Parish School Board	

STUDY/PROJECT INFORMATION FOR HUMAN SUBJECTS COMMITTEE

Describe your study/project in detail for the Human Subjects Committee. Please include the following information.

TITLE: "NASA-Threads"
PROJECT DIRECTOR(S): Heath Tims
EMAIL: htims@latech.edu
PHONE: (318)-257-3770

DEPARTMENT(S): College of Engineering and Science

PURPOSE OF STUDY/PROJECT: The purpose of this study is to determine whether a new, more project based, physics/pre-engineering curriculum encourages more students to pursue science, technology, engineering, and mathematics (STEM) related disciplines, as well as better prepares students for majoring in (STEM) disciplines in college.

SUBJECTS: Teacher (Missy Wooley) and students enrolled in a physics course at Ruston High School (Ruston, LA), Teacher (Marvin Nelson) and students enrolled in a Pre-Engineering course at Benton High School (Benton, LA), Teacher (Brian Lidington) and students enrolled in Pre-Engineering course at Lovejoy ISD (Allen, TX). Attached are memos from the principals of each school stating they are aware of the study taking place.

PROCEDURE: A new project based curriculum will be developed by faculty members in COES at Louisiana Tech University, assistance will be provided by the high school teachers in developing the curriculum. Throughout the school year various surveys and assessments will be conducted on the students' self efficacy towards STEM disciplines.

INSTRUMENTS AND MEASURES TO INSURE PROTECTION OF CONFIDENTIALITY, ANONYMITY: The course assessments as well as various pre-existing surveys (see attachments) will be utilized in performing analysis. All FERPA guidelines will be adhered to and student names will not be included in any report of the study. Complete anonymity and confidentiality will be practiced.

RISKS/ALTERNATIVE TREATMENTS: The participants understand that Louisiana Tech is not able to offer financial compensation nor to absorb the costs of medical treatment should you be injured as a result of participating in this research.

BENEFITS/COMPENSATION: None

SAFEGUARDS OF PHYSICAL AND EMOTIONAL WELL-BEING: This study involves no treatment or physical contact. All information collected from the survey will be held strictly confidential. No one will be allowed access to the survey other than the researchers.

Note: Use the Human Subjects Consent form to briefly summarize information about the study/project to participants and obtain their permission to participate.

Received 1/13/...

APPENDIX C

NASA-THREADS DESIGN

C.1 NASA-Threads Prototype Curriculum

The layout of the prototype curriculum took a different approach than a typical physics course. Instead of the typical course outline where Work and Mechanics is introduced first, the design team decided to shuffle things around and put Electricity and Magnetism first. The reason for placing the Electricity and Magnetism unit before the Work and Mechanics unit was decided for two reasons. First, the curriculum uses the microcontroller as an educational platform throughout the course. Because the platform is an integral part of the active learning components, it is necessary for the students to understand the microcontroller. Throughout the process of learning Electricity and Magnetism fundamentals, the students gain a good understanding of the microcontroller. Secondly, the design team decided to move the Electricity and Magnetism section to the beginning of the course to entice the students with technology. The microcontroller acts as the "hook" that engages the students' interest in learning the material. Students get excited when they can make the microcontroller move; thus, they get excited to learn how they make it move [50].

The Electricity and Magnetism section begins with simple programming of the microcontroller to get students comfortable in programming. The unit then moves into learning how to build a circuit on a breadboard. Students are tasked with projects like creating a landing strip, Figure C-1, and programming a countdown timer using a 7-segment display. Throughout these projects, the students learn about electricity fundamentals, like electron flow, batteries, molecules, and atoms. Additionally, students are introduced to a multimeter which they use to measure quantities of current and voltage. Then, they deductively determine the fundamental equations, instead of the teacher giving them the equations for ohm's law, combining parallel and series circuits, Kirchhoff's voltage and current laws. The students learn about input and output using whisker circuits on the microcontroller. They also learn about capacitors when they use photoresistors to make their microcontroller navigate over a black line. Then, the unit moves more into the magnetism section. The students learn about magnetic fields by building Beakmann motors and speakers using household materials and magnets. Throughout the remainder of the section are more Electricity and Magnetism fundamentals and projects [50-51].

Figure C-1: A NASA-Threads student working on the landing strip project found in the Electricity and Magnetism unit [50].

Following the Electricity and Magnetism unit, the design team felt the natural progression for the curriculum is Work and Mechanics. The lessons begin with an introduction to position, velocity, and acceleration. Within these lessons students are tasked with using a camera to capture a falling ball. The students import the data and use fundamentals to discover the acceleration constant due to gravity. The prototype then contains various Work and Mechanics fundaments such as: 1D and 2D particle motion, atoms and molecules, Newton's Laws of Motion, force components, resultants, among others all coupled with various active learning components. One course concept that ties in fundamentals from the Electricity and Magnetism section is the lesson on mechanical energy. Students are asked to determine the efficiency of the servo motors that are provided with their microcontrollers. Determining the efficiency of the servos requires the students to recall how to calculate electrical work because the servo motors convert electrical energy to mechanical energy. A sample of this lesson is depicted in Figure C-2. The unit continues with more active learning components that relate the Work and Mechanic's fundamentals to tangible and memorable concepts that engage the students [50-51].

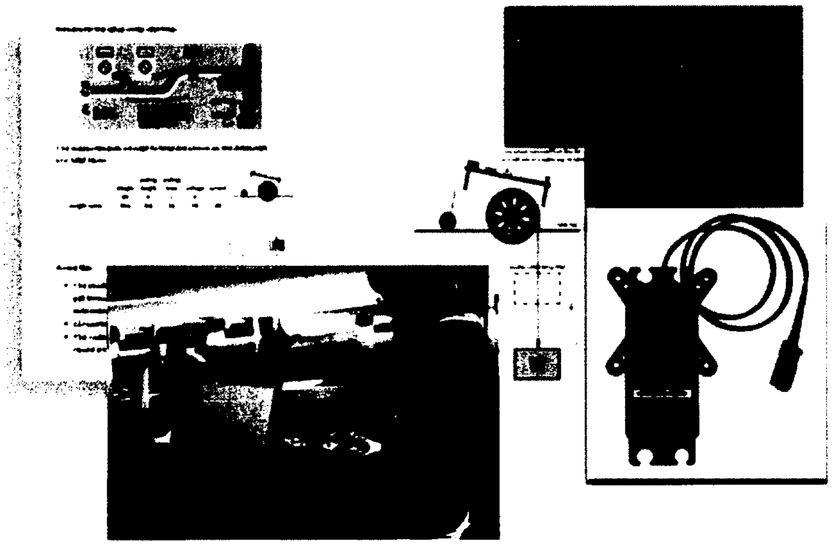

Figure C-2: Partial master notes and picture of student completing servo efficiency project [50].

The prototype curriculum, next, transitions into the Light and Optics unit. After which is the Waves and Sound unit. Much like the first two units in the curriculum, these two units focus heavily on the fundamentals incorporating active learning components interspersed throughout. For instance, in the Waves and Sound unit, an engaging project used to illustrate the fundamental concepts of waves, frequency, and sound is building a guitar, Figure C-3. Students can see and experience the fundamental concepts. In the lesson, students are required to use their knowledge of the fundamentals to calculate the location of the frets on the guitar [50].

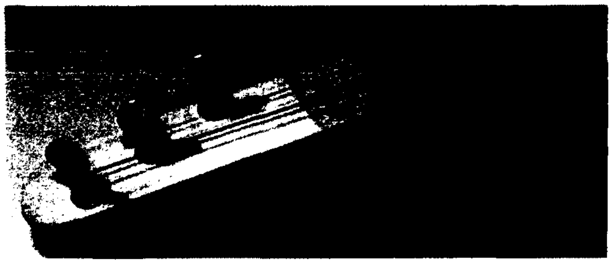

Figure C-3: Picture of guitar built from a lesson found in the NASA-Threads curriculum prototype [50].

The design team built a website, nasathreads.com, to host all prototype curriculum materials [64]. The website provides an easy interface for instructors to access the course content. The lesson plans, master notes, and any additional worksheets, homework assignments, and tests are available via the web. Using the website helped the design team to easily disseminate the material to the teachers [50-51]. Figure C-4 depicts the NASA-Threads website interface, specifically the Electricity and Magnetism section.

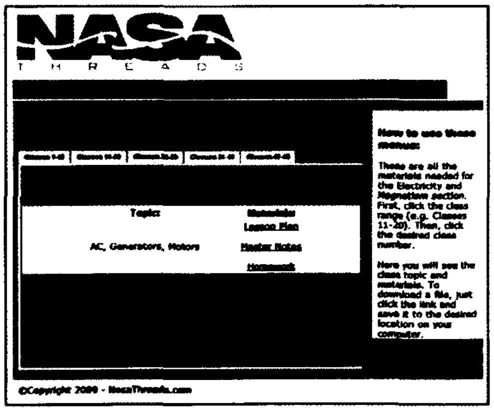

Figure C-4: NASA-Threads website interface [50].

C.2 Survey Results from NASA-Threads Workshop

Throughout the workshops surveys were given to the participants to assess its effectiveness. The results of the surveys were published in a report submitted to Lincoln Parish Schools [65]. The final evaluation surveys which were given at the conclusion of the workshops provided a good summary of the participant's feelings towards the workshops. The survey was formatted using two common survey techniques: 5 point Likert scale and open ended questions. Results from the final evaluation surveys given during the first workshop are in the tables below. The parameters of the 5 point Likert scale used were strongly disagree (SD), disagree (D), undecided (U), agree (A), and strongly agree (SA). Also for each of the responses, the rating average (RA) and the response count (RC) were tabulated. These results were used to assess the effectiveness of the workshop in conveying the new curriculum design to the teachers. The results were also used to make improvements for the following years' workshop as well as potential improvements to the curriculum. This dissemination of the curriculum content to the instructors is a key aspect in design process because the high school teachers are the vessels that transfer the product (course material) to the intended customers (students). Consequently, the effectiveness of the workshops is important to the design team.

Table C-1 is the workshop participants' responses to questions associated with the content of the NASA-threads curriculum presented during the workshop. Out of 23 participants in the survey, there was one participant that responded negatively to the curriculum content. The remaining 22 participants all responded either neutrally or positively. Although one participant felt negatively about the content, the majority of positive responses towards the content helped validate the new curriculum. Many of the open-ended responses were beneficial as well. Through the responses, it was clear, reading through the open-ended responses that the material presented a level of rigor that the students are not accustomed to handling. They did, however, feel that it was within their students' ability to step up to the rigor and succeed in the course.

Table C-1: The workshop participants' responses to questions content of the NASA-threads curriculum [65].

NASA Threads 2010 Summer Institute: Final Evaluation - Question 1							
For each of the following areas, please indicate your reaction to the following statement. The content delivered during the workshop session:							
Answer Options	**SD**	**D**	**U**	**A**	**SA**	**RA**	**RC**
A. is/will be applicable to my teaching	1	0	0	6	16	4.57	23
B. was well organized	1	0	2	6	14	4.39	23
C. practical to my needs an interests	1	0	0	8	14	4.48	23
D. was at the appropriate knowledge level	1	0	3	10	9	4.13	23
E. was connected to effective activities	1	0	0	6	16	4.57	23
F. was illustrated by/with useful visual aids and handouts	1	0	1	5	16	4.52	23
G. was at the appropriate skill level	1	0	2	7	13	4.35	23
Additional comments are welcome							5

Additional comments are welcome	
1	great session. The presenter was very very good
2	Some activities I felt were beyond the level of students that this will be affecting. Just remember that these are still high school students and not college students. There is a maturity level to consider.
3	This will be extremely helpful to me in my teaching this year. I am hopeful that this will increase the enrollment in physics at my school and also the number of students who elect STEM majors.
4	very helpful
5	It will take me some time to work through the math... I understand it, but am not used to explaining so many steps. However, it is well within my and my students' abilities.

Table C-2 identifies workshop participants' feelings towards the presenters of the workshop. Evaluating the presenters at the workshop was not a means to single out a certain presenter, but instead determine strengths and weakness to improve the workshops in the future. One participant answered in a negative manner to the questions relating to the presenters and the remaining 22 participants answered either neutrally or positively. The positive responses and the answers from the open-ended question reveal that the presenters did a good job throughout the workshop. One participant noted that some instructors were clearer than others. By identifying presentation clarity as an issue, those presentations with issues were revisited and amended for future workshops. The first workshop allowed the curriculum designers to present the material and learn the right and wrong ways to present to the instructors who will be teaching the course.

Table C-2: The participants' feelings towards the presenters of the workshop [65].

NASA Threads 2010 Summer Institute: Final Evaluation - Question 2							
For each of the following areas, please indicate your reaction to the following statement. The instructors/presenters:							
Answer Options	**SD**	**D**	**U**	**A**	**SA**	**RA**	**RC**
A. demonstrated thorough knowledge of the workshop content	1	0	0	4	18	4.65	23
B. demonstrated enthusiasm for the workshop content	1	0	0	2	20	4.74	23
C. delivered the content in a clear and understandable fashion	1	0	3	10	9	4.13	23
D. responded effectively to questions	1	0	0	3	19	4.70	23
E. incorporated useful examples	1	0	0	5	17	4.61	23
F. modeled effective pedagogy	1	0	2	6	14	4.39	23
G. created a positive learning environment	1	0	0	3	19	4.70	23
Additional comments are welcome							5

Additional comments are welcome	
1	All of the Tech staff were great
2	some instructors were clearer than others
3	they are awesome!!!!!
4	great instructors
5	All instructors were great - understandable and enthusiastic.

Table C-3 identified the participants' general feelings towards the workshop. One participant again responded negatively to all questions in this section of the survey. The remaining 22 participants responded either neutrally or positively except for two of the questions. Three participants (in addition to the previously identified negative comment) commented negatively on the pacing of the workshop. Two participants also commented negatively towards the time allocated to presentations and group activities. Both of the questions with some negative evaluations related to pacing of the workshop. Using the survey to identify the pacing issues helped in the creating a better schedule for future workshops that gave more appropriate time for group activities and presentations. One participant noted the integrated nature of the workshop and having excited workshop faculty and staff were positive points they enjoyed.

Table C-3: The workshop participants' general feelings towards the workshop [65].

NASA Threads 2010 Summer Institute: Final Evaluation - Question 3							
For each of the following areas, please indicate your reaction to the following statement. The workshop:							
Answer Options	**SD**	**D**	**U**	**A**	**SA**	**RA**	**RC**
A. was well organized and followed a logical order	1	0	2	7	13	4.35	23
B. met the proposed objectives/outcomes	1	0	1	8	13	4.39	23
C. had a positive effect on your knowledge of the workshop content	1	0	0	6	16	4.57	23
D. provided satisfactory food, snacks, and beverages	1	0	1	6	15	4.48	23
E. had a positive effect on your confidence in teaching the workshop content	1	0	1	7	14	4.43	23
F. facilities were appropriate and satisfactory	1	0	0	6	16	4.57	23

G. had a positive effect on your enthusiasm for teaching the workshop content	1	0	0	7	15	4.52	23
H. was paced appropriately	1	3	1	11	7	3.87	23
I. had efficient and informative pre-workshop administration	1	0	2	8	12	4.3	23
J. had appropriate time allocated to presentations and interactive group work (activities)	1	2	1	8	11	4.13	23
K. was a valuable learning experience	1	0	0	4	18	4.65	23
Additional comments are welcome							3

Additional comments are welcome	
1	Hospitality was great!
2	I love the integrated approach....ME's teaching electronics, etc. What a great group of colleagues who obviously like working together to improve the process!
3	It would have been nice if one week had been at the end of June and the other week at the end of July. The last week of July is too close to the start of school.

Table C-4 identifies the aspects of the workshop that the participants felt were most useful. This section of the survey was a simple open-ended question that prompted the participants to identify the most useful components of the workshop. The majority of the participants responded that working through the activities during the workshop was the most useful. It gave them the experience to learn the new technology as well as allowed them to have the struggles and the "ah ha" moments that will help them to empathize with the students as they work through the curriculum.

Table C-4: The aspects of the workshop participants felt was most useful [65].

NASA Threads 2010 Summer Institute: Final Evaluation - Question 4		
Which element(s) of the Summer Institute was the most useful? Please explain your response.		
Number		Response Text
1		The activities.
2		all were useful
3		All of the activities.
4		The overall organization and activities presented at the institute were effective in teaching us how to integrate this curriculum in our classroom.
5		Working through activites to gain some experience with hardware and software.
6		all of the activities will be great in the classroom
7		Boe Bot instruction. Execution and management of projects.
8		The projects helped me see what my students may encounter during the year.
9		The hands on projects were the most useful. It is the area that I will have the most trouble with.
10		The activities really opened my eyes to more ways to incorporate project based learning.
11		Great workshop
12		The vast content that was presented.
13		The hands on activities
14		Group work and doing the activities together. This should be very helpful once school starts.
15		Working through the projects
16		The commitment to project based learning and the chance design and build solutions to problems - the students will be highly motivated!
17		I anticipate using everything that was presented - not quite sure how or when yet. May also use some modified activities in my Intro to Engineering class. I needed the instruction and introduction to programming and Excel.
18		exposure to the program and refreshing my knowledge base.
19		I have been exposed to presenting the old concepts with new ways by using technology.
20		hands on activities
21		doing the activities was most useful, seeing what should happen and what could go wrong
22		Using technology and Excel
23		I believe that the activities and the analysis were valuable and useful.

Table C-5 identifies the aspects of the workshop that the participants felt were least useful. Much like the fourth section in the survey, this section of the survey was a simple open-ended question that prompted the participants to identify the least useful components of the workshop. Although many participants responded with "none," some participants had beneficial criticism. Some mentioned, again, issues related to pacing, noting the workshop was sometimes too fast and other times to too slow. Acknowledging that pacing was an issue, adjustments were made for future workshops.

Table C-5: The aspects of the workshop participants felt was least useful [65].

NASA Threads 2010 Summer Institute: Final Evaluation -Question 5		
Which element(s) of the Summer Institute was the least useful? Please explain your response.		
Number		**Response Text**
1		None.
2		all were useful
3		Some of the lectures.
4		The theory discussions were helpful, yet very dry and boring.
5		None
6		it was all useful, a touch heavy on spread-sheeting
7		Doing problems.
8		I wish I could have seen the master notes and handouts at the same time as the project/concepts were discussed so I could compare what we are given to what we need to know.
9		none
10		The original excel lessons were not beneficial to me personally. However, the excel lessons later were far more developed and in-depth and taught me things I never knew
11		n/a
12		nothing
13		Some lectures I felt were beyond the appropriate level.
14		None.
15		None
16		To help the teachers follow along with the Tech professor guiding us through a lesson, I the teachers be given an itinerary for the week that states which lessons will be covered so that they can read over the master notes beforehand.
17		Right now I think I will be able to use everything but since I am not experienced in this, I don't know.
18		sometimes a little too much too fast and others times there was too much down time. Work on pacing of activities.
19		I would prefer this workshop to be planned at least a month long.
20		more explanation of the physic/math
21		Some breaks could perhaps be shortened a little in order to end earlier in the evenings.
22		none
23		na

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VITA

Krystal Corbett graduated with her BS in Mechanical Engineering at Louisiana Tech University in 2008, having served as president of Tau Beta Pi her senior year. In her second year of graduate study, she began her dissertation research as part of the NASA-Threads curriculum design project. During this same time, she taught, with full responsibility, in the engineering thread of the freshman Integrated Engineering Curriculum at Louisiana Tech. Receiving her MS in Mechanical Engineering in 2010, Ms. Corbett joined the design team for the mathematics content thread of the Freshman Enrichment Program in the College of Engineering and Science. She subsequently taught in the mathematics thread of the freshman Integrated Engineering Curriculum. In 2012, Ms. Corbett obtained her MS in Mathematics. Currently she is completing her PhD in Engineering at Louisiana Tech.

Throughout her tenure at Louisiana Tech, Ms. Corbett has been heavily involved in numerous educational initiatives. She has been an integral part in the development of the NASA-Threads High School Physics curriculum as well as the Cyber Science curriculum. In both curricula, she was responsible for translating much of the STEM content into master notes, lesson plans, and supplemental material that were easily implemented by high school teachers. Moreover, she organized and facilitated key components of professional development workshops for the courses. Ms. Corbett's background in both engineering and mathematics, as well as her research in engineering education, allowed her to fill a critical need in the Cyber Discovery initiative sponsored by the Cyber Innovation Center. She is part of the national roll-out team for Cyber Discovery and will help lead curricular design initiatives connected to that program.