

Connected Mechanical Engineering curriculum through a  
Fundamental Learning Integration Platform

by

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## **Abstract**

To keep students engaged in the learning process, educational engineering institutions need to enhance their curricula. Courses within an undergraduate curriculum need to be connected in a way that is meaningful and promotes student engagement through hands-on learning. Courses are currently designed like silos of knowledge with no connection between them, yet, there needs to be a realistic and practical tie between them. Prior research that addresses course integration, hands-on learning and student engagement has guided the development of this thesis.

Building on prior research, a Fundamental Learning Integration Platform (FLIP) has been developed that uses a physical object to integrate traditionally mechanical engineering taught courses with the use of a single ubiquitous object. This learning platform has three desired outcomes: 1) it connects the entire curriculum, 2) it creates a physical connection between theoretical and practical engineering concepts, and 3) it engages and includes every student in the learning process.

After identifying research to guide the development of the FLIP as well as identifying courses in a mechanical engineering curriculum, a desktop steam engine was developed and is shown that it is applicable to each course. This physical object acts as the FLIP. Ultimately, it will create a physical connection between theoretical and practical engineering concepts while integrating courses together and actively engaging each student in the learning process. Utilizing the same assessment methods used in the identified research, higher retention rates, increased passing rates of the Fundamentals of Engineering exam, and increased student inclusion in the classroom are all desired measurables of the FLIP.

The results of this research have provided a well-developed FLIP that utilizes a physical object to increase student engagement while integrating traditional mechanical engineering courses together.

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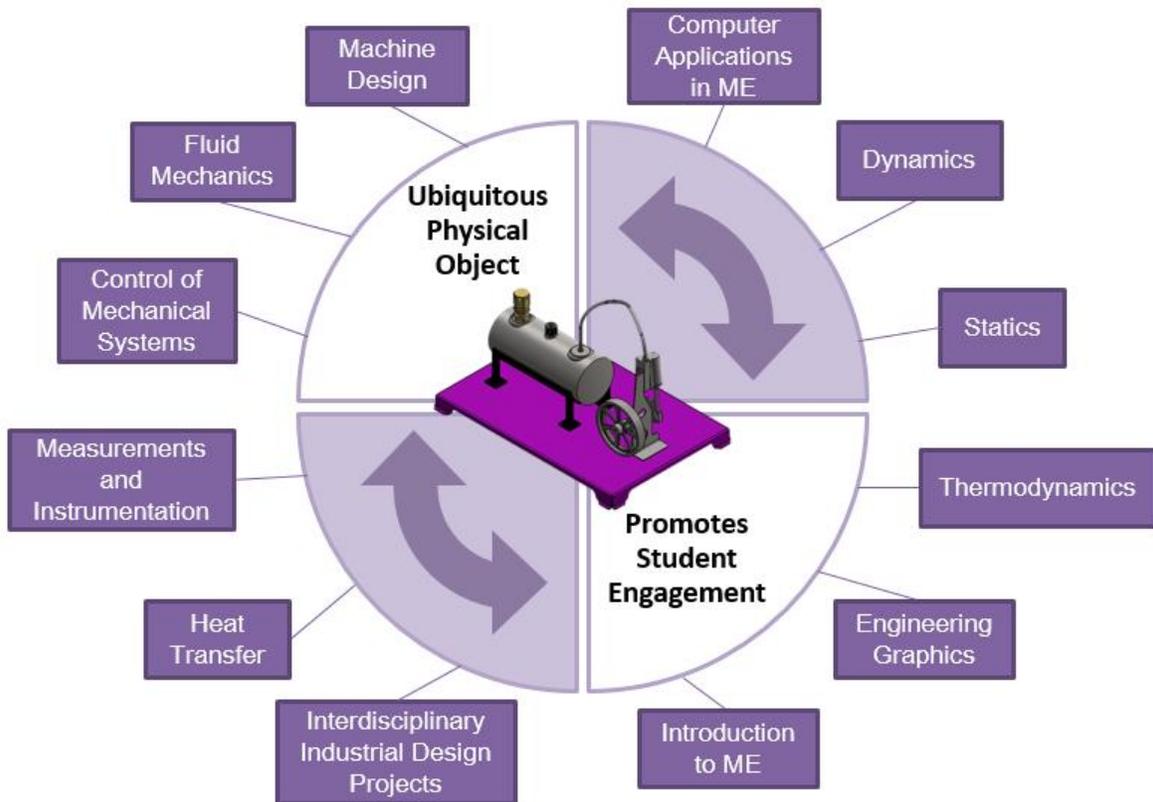
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# Chapter 1 - Introduction

This thesis presents a hands-on learning object that can ubiquitously connect courses throughout a mechanical engineering curriculum. I call the object a fundamental learning integration platform (FLIP), as it integrates all of the courses in a mechanical engineering department by using a common theme of how latent energy can be transformed by a physical object into useful energy. This theme is one of the fundamental principles of mechanical engineering. Combining concepts related to integrated curricula, physical objects, and student engagement as shown in Figure 1, it will result in an enhanced mechanical engineering curriculum.



**Figure 1: Enhanced Curricula via FLIP**

Throughout an engineering curriculum, there should be a realistic and practical connection between courses such that each course is not represented as an individual silo of knowledge<sup>1</sup>. Without these connections, students are unable to transfer and structure their knowledge in a logical way<sup>1</sup>. Thus, the FLIP was developed such that it could be implemented into any typical course in a mechanical engineering curriculum. Similar to how the FLIP will be

implemented into courses, literature shows how project-based scenarios are often used to connect together course concepts that are individually important for the students to understand. Since the FLIP will be used in each course, students will be able to relate content from one course to another by way of the FLIP.

The ubiquitous physical object of the FLIP creates a strong connection to hands-on learning. Research has shown that hands-on learning increases student retention<sup>2</sup>. Similar to how the FLIP will be implemented, diverse courses such as mechanical design and thermodynamics have been integrated by the implementation of a physical hybrid powertrain project<sup>3</sup>. The physical powertrain project integrated six courses together over a three-year span. Another example of hands-on learning research is how a desktop steam engine was used at Rowan University in two junior-level courses. Students associated with this hands-on project indicated that they felt an increase in their knowledge of course fundamentals<sup>4</sup>.

The development of the FLIP was guided from previous research such that implementation of the FLIP would result in an increase in student engagement in the classroom. Research by Dym<sup>5</sup> discusses how project-based learning has been shown to increase student engagement and performance of all students involved. Furthermore, course integrations similar to how the FLIP integrates courses have been shown by the literature to promote student engagement<sup>6</sup>.

Guidance from the literature has identified how other institutions and researchers have addressed the lack of course integration, hands-on learning, and student engagement. Building from their research, this paper presents how an entire curriculum can be connected with the use of a physical object by utilizing hands-on learning while increasing student engagement.

## **Chapter 2 - Literature Review**

In this literature review, relevant research is presented that serves as a framework for the FLIP. This framework is divided into three categories: curriculum integration, physical objects, and student engagement. For each category, examples of relevant curricula and how they apply to this thesis are discussed. The identified research guides how the FLIP is developed and supports the benefits of implementing the FLIP.

### **Curriculum Integration**

In the complexity of planning a curriculum, there are many questions to be answered. Researchers have paid much attention to learning objectives, course content, teaching methods, and educational strategies such as problem-based learning<sup>7</sup>. An area with less focus has been the question of the overall integration of a curriculum<sup>6</sup>. A traditional view is that an engineering curriculum is comprised of a series of classes. Lately there is a growing tendency to look at the overall aims or objectives of the curriculum, instead of the individual courses<sup>6</sup>. While the content of an entire curriculum cannot be integrated, a curriculum can be centered around a common theme as given by the FLIP.

Questions have been repeatedly raised about whether neatly compartmentalized courses can provide the ability for students to structure their knowledge across course and disciplinary boundaries<sup>6</sup>. Engineering curricula are designed such that students take a wide breadth of courses each semester. Engineering faculty expect students to transfer what they learn to following engineering courses. Although transfer was anticipated when engineering curricula were designed, Froyd states that faculty members suggest the transfer of knowledge is not sufficiently occurring<sup>6</sup>. Instead of relying on students to create the knowledge connections between courses, the FLIP discussed in this thesis will facilitate the transfer of knowledge that students require.

Curriculum integration is the act of creating an explicit connection between courses within a curriculum. With courses designed like silos of knowledge, there must be a realistic and practical tie between them for students to see the relevance between them<sup>1</sup>. Comments from students suggest that they see few connections between math, science, and their future careers<sup>6</sup>. The purpose of the FLIP is to connect courses within a curriculum in a way that is meaningful and promotes student engagement through hands-on learning. Previous work on integrating the

course content of mechanical engineering at multiple institutions have resulted in improved grades<sup>8</sup>, increased student satisfaction<sup>9</sup>, and positive reactions from students<sup>10</sup>. Examples of curricula that directly correlate to how the FLIP will integrate courses are outlined below.

Similar to how the FLIP will integrate an entire curriculum together, researchers have conducted the effects of course integration on a smaller scale. Roemer<sup>7</sup> developed a curriculum implemented at the University of Utah that connected the first two years of the mechanical engineering curriculum by using a four-course sequence. Objectives included motivating engineering students to remain in school, helping non-traditional students in their learning, and increasing the retention and application of relevant material<sup>7</sup>. Assessment of these objectives was not outlined, but the program addressed opinions that current students have lots of technological experience instead of hands-on experience.

The FLIP will integrate courses in such a way that the only connection is the physical object. Thus, it must be applicable and relatable to students on various knowledge levels. This is in alignment with Hardin<sup>11</sup> when he developed a project at Virginia Military Institute where senior students in a capstone design class worked with engineering students earlier in the program to help develop their capstone projects. This project provided senior students with numerous technical and managerial opportunities for leadership as well as provided hands-on engineering experiences for lower level engineering students<sup>11</sup>.

Research has also been conducted between engineering and non-engineering courses at Texas A&M University. This aligns with the future idea of how the FLIP could potentially be implemented on a university level. One hundred students participated in an investigation that integrated physics, engineering design, calculus, English, and chemistry courses. Though evaluations demonstrated little change between the test group and the traditional students, student surveys showed an increase in understanding of material and concepts<sup>12</sup>.

The FLIP proposed in this thesis will initiate change in a mechanical engineering curriculum. Prior research showing the positive outcomes of increased student satisfaction and increased retention due to integrated curricula supports the effort to develop a FLIP for mechanical engineering curricula. The implementation of the FLIP will lead to students seeing the relevance and importance of the courses they take due to the integration between courses within a mechanical engineering curriculum.

## Physical Objects

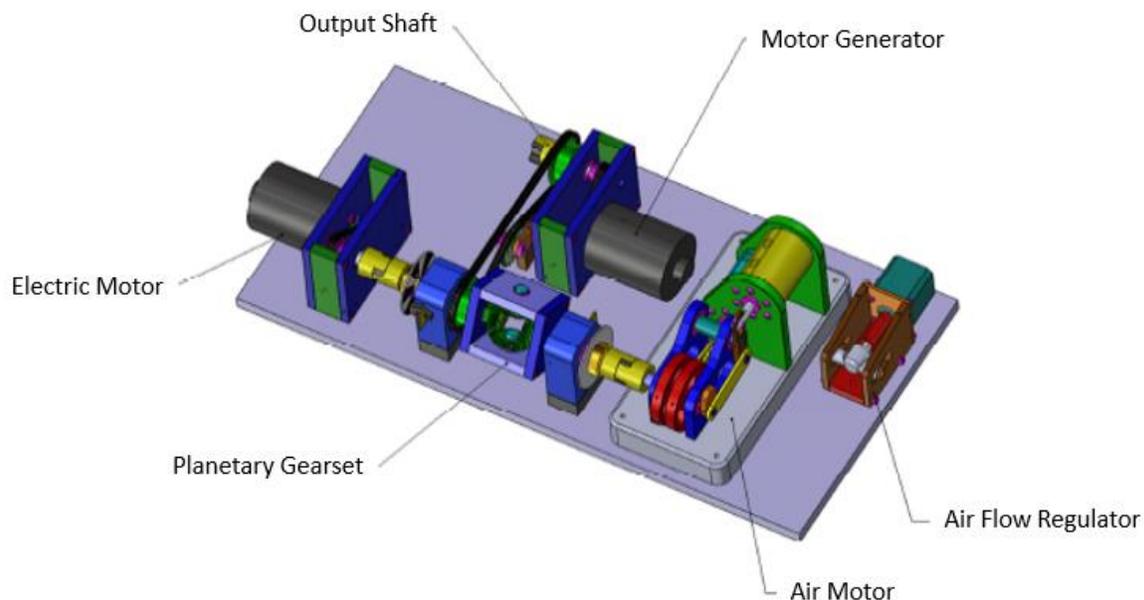
In order to learn new knowledge, it needs to be connected to and structured around prior knowledge. This can be done with the FLIP as a physical object is one way to promote hands-on learning. This hands-on learning can be done in an active sense with students interacting with the physical object, or passively by using the physical object to supplement concepts taught in the classroom. Functional magnetic resonance imaging studies have indicated that people need to make connections between their existing knowledge and a new word or image to remember it<sup>6</sup>. With the use of a ubiquitous physical object, students will have such an image to connect to. As stated by Sheppard, “There is no substitute for rolling up your sleeves and digging in. I believe that we ‘see’ with our hands as well as with our eyes.”<sup>13</sup> Numerous studies from the University of Tennessee<sup>14</sup>, University of Alberta<sup>15</sup>, Carnegie Mellon University<sup>16</sup>, and the University of Colorado at Boulder<sup>17</sup> have shown that the use of physical objects to convey theory and concepts has positive effects on student learning abilities. Each of these studies similarly conclude that hands-on pedagogy with the use of physical objects can show an increase in student retention, critical thinking skills, and knowledge retention<sup>19-22</sup>.

The implementation of hands-on engineering at the University of Colorado at Boulder has increased first-year retention rates from 55% to 80%<sup>2</sup>. First and second year students take an engineering projects course where they experience the engineering design process in a hands-on way. Through the use of surveys, students overwhelmingly report that this course gives meaning to their physics and calculus courses<sup>2</sup>.

In some courses, the FLIP will be used to generate knowledge. This concept is similar to a mechanical dissection course at Tuskegee University where first-year students study the function of a mechanical system by dismantling it in order to see how its specific function is realized. This hands-on application with the use of simple mechanical devices has been shown to provide the foundation for better understanding in upper level courses<sup>18</sup>. Mechanical dissection courses are also implemented at Stanford University where students give presentations on how their dissected objects tie to theories and concepts<sup>13</sup>.

The FLIP will implement a physical object into each course in a curriculum. Similar research was conducted on a partial curriculum at Rowan University. Constans uses a long-term green design project to give students hands-on experience with a five semester core curriculum<sup>3</sup>. Each semester, students look at a different design aspect of a hybrid powertrain, as shown in

Figure 2. Through this project, students are required to rely on their previous knowledge to further the design of the powertrain<sup>3</sup>. Since students work on the project for five consecutive semesters, they become familiar with the operation of the powertrain. The powertrain acts as a physical object that students can connect knowledge to as they progress through their classes<sup>3</sup>. This directly relates to the FLIP as students will be similarly using and re-designing the same object throughout a curriculum.



**Figure 2: Physical Hybrid-Electric Powertrain<sup>3</sup>**

Similar to the FLIP object presented in this thesis, the use of a physical steam engine as a teaching tool was investigated at Rowan University. This investigation integrated two junior-level mechanical engineering courses with the use of a steam engine design project. Students from each team joined together to design a desktop steam engine. Examples of their steam engines are shown in Figure 3. They relied on their knowledge from previous courses, and also conducted research regarding steam engines<sup>4</sup>. With the use of student surveys, it was indicated that the students felt an increase in their knowledge of course fundamentals<sup>4</sup>. The FLIP builds from this research as it will be utilized on more than two courses.



**Figure 3: Examples of Student Designed and Built Steam Engines<sup>4</sup>**

It has been shown that the use of physical objects similar to the FLIP in a curriculum directly affects student success. Students report that they feel a connection between theoretical and practical engineering. With the implementation of the FLIP, students will be able to tie and relate all of the content of the mechanical engineering curriculum to the ubiquitous physical object. The FLIP utilizing a physical object will promote hands-on learning that will ultimately lead to enhanced mechanical engineering curricula.

### **Student Engagement**

For a curriculum to be successful, students must be engaged in the learning process. Educators, researchers, and policy makers have advocated student engagement as an essential aspect of meaningful learning<sup>19</sup>. Research shows that low percentages of engineering students remain in engineering one year after matriculation<sup>6</sup>. For example, only sixty percent of students at Indiana University - Purdue University Fort Wayne are retained after two years<sup>20</sup>. The FLIP is guided by the research identified below to result in increased student engagement.

One way to engage students is to promote elements such as data analysis in a traditional lecture setting. Since many mechanical engineering courses do not have an associated lab, the FLIP relies on previously recorded experimental data for the students to analyze. Research similar to this was done at Miami University with the use of online learning modules to increase student engagement. Each module contains educational material in specially developed multimedia formats containing previous experimental and research data. Students compare this data to already learned theoretical knowledge and compare the results. This study resulted in

students having a higher level of critical thinking ability as well as having the feeling of research-based learning<sup>21</sup>.

Another well documented way to improve student engagement is through project-based learning. Instructors may choose to implement the FLIP similarly to the research done by Dym that discusses the implementation of project-based learning to first-year students. Enhanced student interest in engineering, increased retention rates, motivated learning in upper division engineering science courses, and enhanced performance in capstone design courses were all conclusions drawn from this research<sup>5</sup>. Similar conclusions were drawn from project-based research at Worcester Polytechnic Institute where less than 10% of students changed majors while participating in the project-based curriculum versus 20% of students changed majors from the control group<sup>22</sup>.

For the curriculum proposed in this thesis to succeed, students must be engaged in the learning process. Implementation of the FLIP is guided and built from previous research outlined above. As shown above, the FLIP has the potential to create a hands-on learning environment as well as increasing student engagement.

Course integrations have been shown to increase retention rates. The use of physical objects through hands-on learning has been evaluated to have an increase in student critical thinking skills. Methods for increasing student engagement have also been shown to have a positive effect on student success. The FLIP proposed in this thesis is guided by and expands on the reviewed literature by implementing a ubiquitous physical object that will be used to integrate all courses in a mechanical engineering curricula. A summary of relevant research with identified results is given in Table 1.

**Table 1: Literature Review Summary**

**Curriculum Integration**

| <b>Institution:</b>                       | <b>Implementation:</b>                                   | <b>Results:</b>  |
|---|--|--|
| University of Utah <sup>7</sup>           | Integration of first two years in a four-course sequence | Improve graduates' professional skills<br>Override "Design as knowledge" philosophy<br>Increased hands-on learning |
| Virginia Military Institute <sup>11</sup> | Senior capstone integrated with first-year course        | Hands-on learning for first-year students<br>Seniors gained managerial/leadership opportunities                    |
| Texas A&M <sup>12</sup>                   | Five course integration                                  | Increased understanding of materials<br>Higher retention rates<br>Higher percentage of students passing courses    |

**Physical Objects**

| <b>Institution:</b>                            | <b>Implementation:</b>                | <b>Results:</b>  |
|--|---------------------------------------|--|
| University of Colorado at Boulder <sup>2</sup> | First-year hands-on engineering       | Increased retention rates (55%->80%)<br>Students signify meaning in their courses  |
| Stanford University <sup>13</sup>              | Dissection Course                     | Understanding of mechanical artifacts<br>Increased critical thinking skills<br>Power of clear, concise communication                   |
| Rowan University <sup>4</sup>                  | Course Integration with Steam Engines | Related knowledge from previous courses<br>Increased feeling of knowledge of course fundamentals<br>Development of team working skills |

**Student Engagement**

| <b>Institution:</b>                           | <b>Implementation:</b>             | <b>Results:</b>   |
|---|------------------------------------|---|
| Dym (Researcher) <sup>5</sup>                 | First-year project-based learning  | Graduates will be able to practice in industry<br>Motivated learning in upper-level courses<br>Enhanced student interest in engineering |
| Worcester Polytechnic Institute <sup>22</sup> | Second-year project-based learning | Increased student retention<br>Decreased segmented learning<br>Cost effective learning for students with diverse backgrounds            |
| Miami University <sup>21</sup>                | Online learning modules            | Increased critical thinking skills<br>Encouraged independent learning   |

## **Research Question**

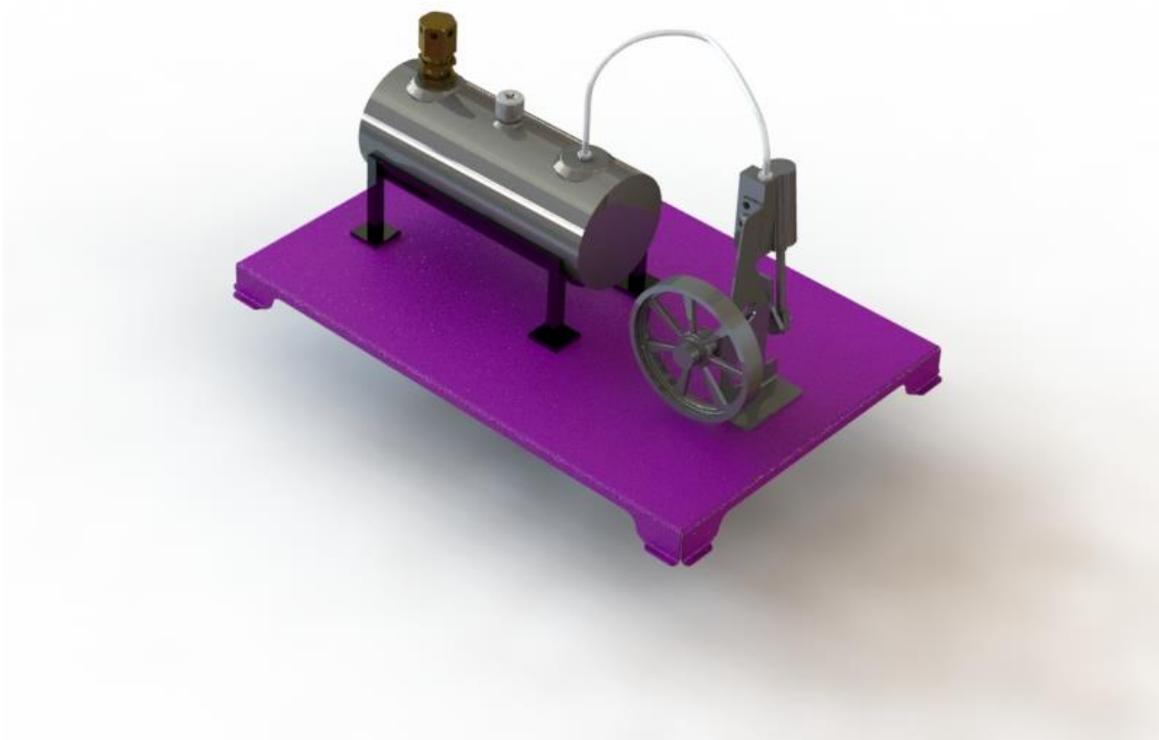
The following research question motivates this study:

How can a common physical object be used to integrate core mechanical engineering courses?

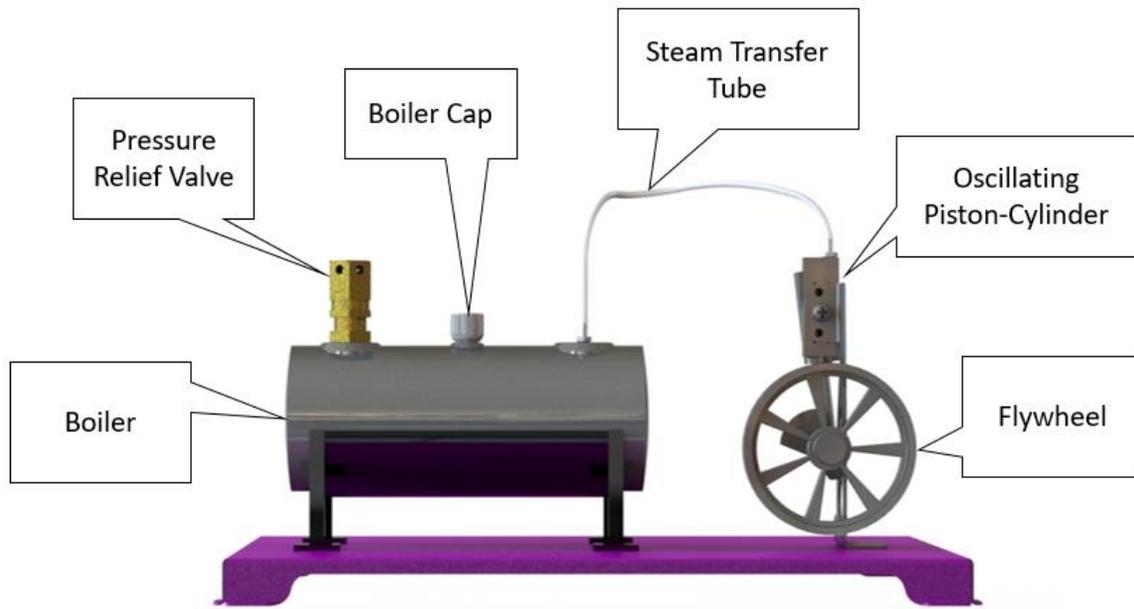
## Chapter 3 - Example FLIP Definition

The concept of a FLIP was built from and guided by previous research of course integration, using physical objects in the classroom, and increasing student engagement. The FLIP utilizes a single physical object that is used to increase student knowledge retention while being applicable to each course in a mechanical engineering curriculum. The implementation of the object into each course will further engage each student in the learning process. Serving as a moving knowledge threshold, it will bring each student in a course to the same common knowledge threshold. To give an example of a FLIP, this thesis will use a desktop steam engine as the ubiquitous physical object.

Steam engines take latent heat energy and convert it into useful kinetic energy. Although power cycles can be quite complex, the general concepts behind them are quite simple and can be understood by first-year engineering students. A schematic of the steam engine model proposed is shown in Figure 4.

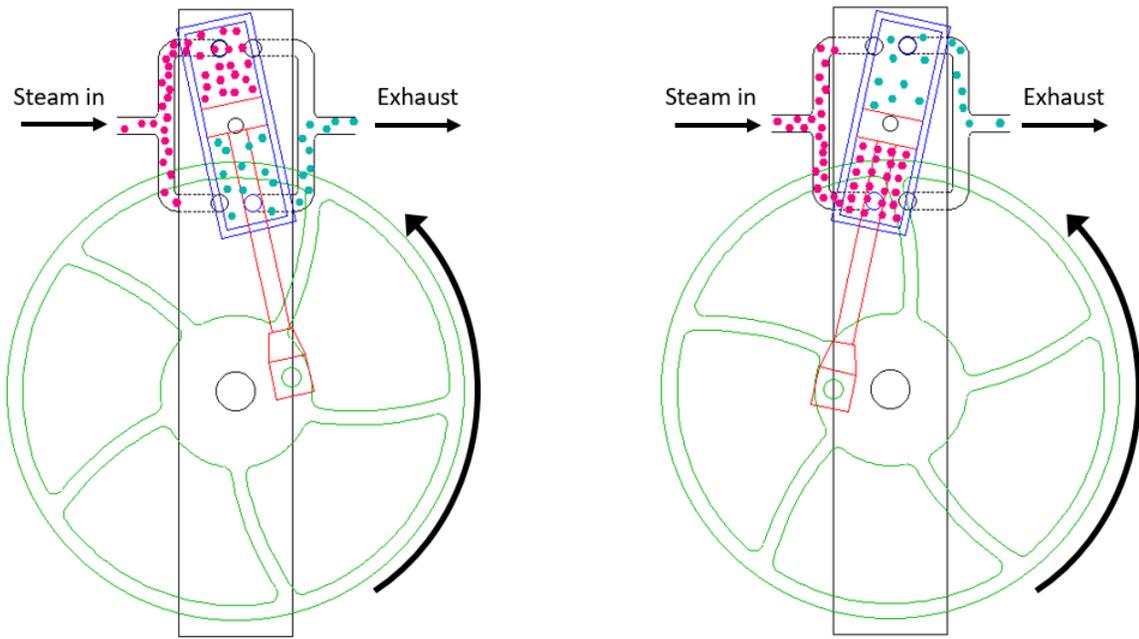


**Figure 4: Proposed FLIP**

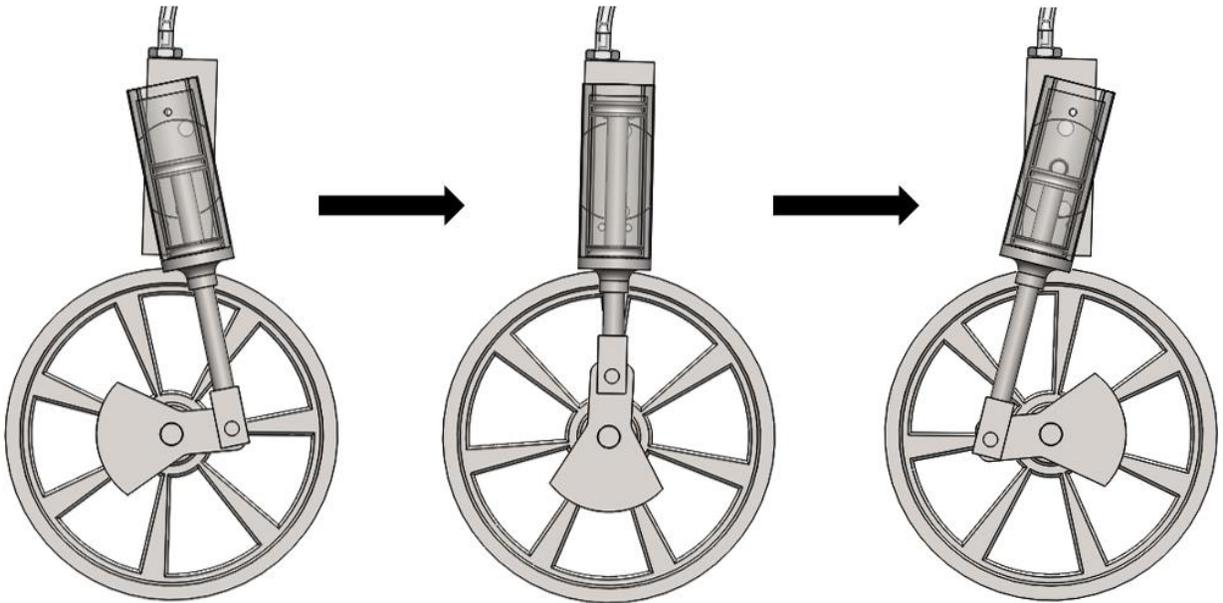


**Figure 5: Proposed FLIP Schematic**

Steam engines heat a working fluid (such as water) in a chamber called a boiler. As the fluid is heated, it builds pressure in the boiler that is transferred to the piston-cylinder via the steam transfer tube. This particular engine design is unable to overcome the static friction of the flywheel. Thus, the flywheel must be manually spun to start the engine. Once the flywheel is spinning, the pressure from the boiler keeps the engine running. This engine has a two-sided piston with an inlet and exhaust port both on each side. At any given time, one side of the piston is at atmospheric pressure while the other side is at the boiler pressure. As the flywheel spins, the piston-cylinder oscillates (or rocks) to the other side switching which port is open. Thus, the side of the piston at the boiler pressure is switched to the other side. The piston-cylinder oscillates (Or rocks) back and forth continually switching which port is open. A diagram of this process is shown in Figures 6 and 7.

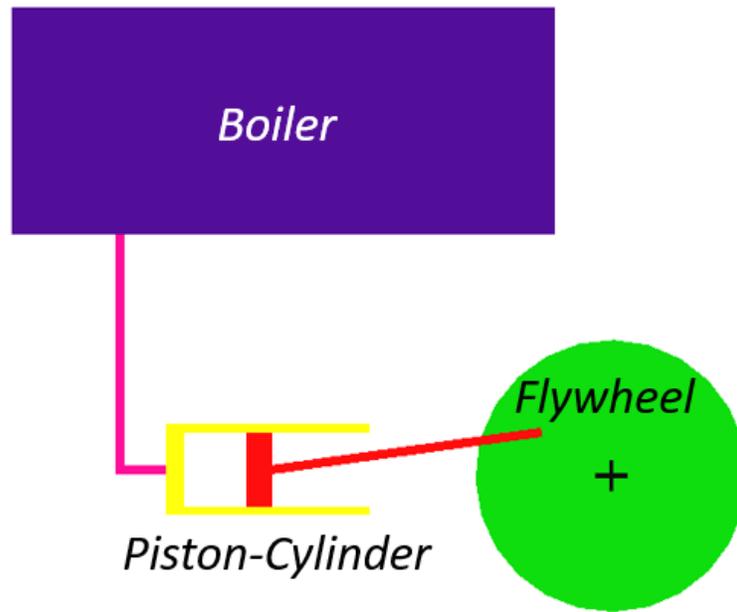


**Figure 6: Oscillating Cylinder Steam Engine<sup>23</sup>**



**Figure 7: FLIP Cylinder Oscillation**

The FLIP example used in this thesis is centered around the use of a steam engine in a curriculum. Acting as the FLIP, this steam engine must be applicable to each course in a mechanical engineering curriculum. For clarity, the simplified schematic of the steam engine shown in Figure 8 will be used in the discussion.

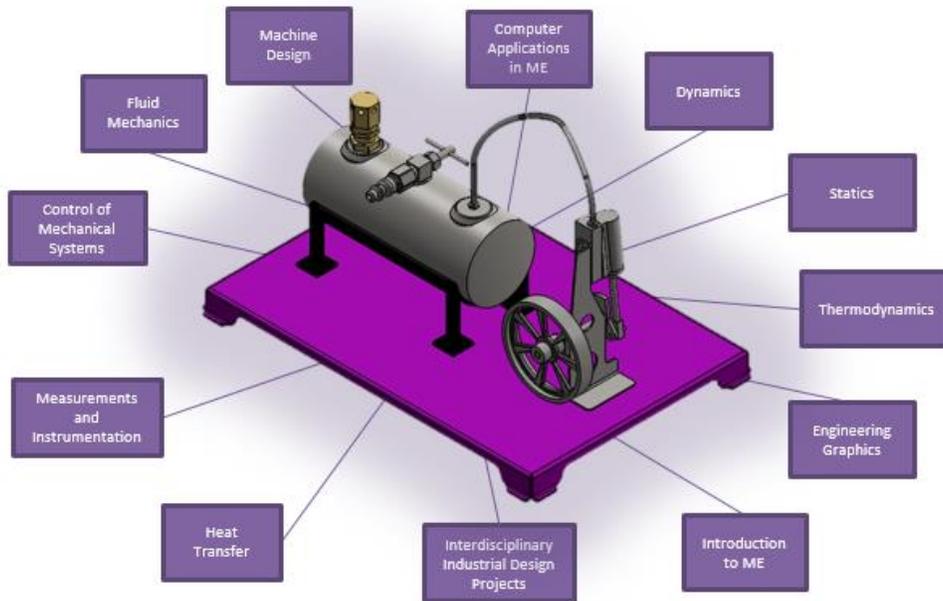


**Figure 8: Simplified FLIP Schematic**

Showing the boiler, piston-cylinder, and flywheel, this figure will be used to demonstrate the relationship of the steam engine to each course discussed in the next chapter.

## Chapter 4 - Curriculum Implementation

In this thesis, a steam engine will serve as the FLIP. This chapter will show how this ubiquitous physical object can be implemented into typical mechanical engineering courses. Each course outline will contain a brief course description, course prerequisites, and implementation strategies.



**Figure 9: FLIP Integration of Curriculum**

The methodology used to determine the courses that would be discussed in this project was centered around the desire to implement the FLIP at Kansas State University in the Mechanical and Nuclear Engineering Department. To validate that the FLIP can be implemented outside of Kansas State, Midwestern institutions as well as institutions identified in the research were evaluated. Courses offered by each institution's mechanical engineering department are given in the table below with similar courses highlighted. Using the Kansas State University course catalog to identify key course concepts, implementation of the FLIP into each of these highlighted courses will be discussed. In each discussion, a brief description of course content, required prerequisites, and a FLIP implementation strategy will be given. Identifying prerequisites for each course is important with regards to having students rely on previous knowledge. The FLIP is used to integrate each course together, yet, instructors can only rely on material that is from a prerequisite course.

A brief example of how the FLIP could be implemented into each course will be given. Yet, it is up to the instructor to determine how the FLIP should be implemented into each of the courses. An instructor may use the FLIP as a talking point where the students relate to it, yet, they physically do not touch it. Likewise, it may be implemented such that students are actively engaging with the FLIP in a hands-on learning environment. Furthermore, an instructor may want students to work individually with the FLIP while other instructors may want students to work in groups. Thus, the examples given are not comprehensive, yet, they give possible implementation strategies for instructors to build upon.

**Table 2: Mechanical Engineering Curricula Across Multiple Institutions**

| University: | Missouri S&T <sup>24</sup>             | Texas A&M <sup>25</sup>                         | University of Nebraska-Lincoln <sup>26</sup> | University of Kansas <sup>27</sup>              | Kansas State University <sup>28</sup>           |  |
|-------------|--|---|--|---|---|--|
| First Year  | Introduction to Mechanical Engineering | Introduction to Mechanical Engineering          | Introduction to Mechanical Engineering       | Introduction to Mechanical Engineering          | Introduction to Mechanical Engineering          |  |
| ↓           | Engineering Graphics                   | Engineering Mechanics                           | Engineering Graphics                         | Computer Applications in Mechanical Engineering | Engineering Graphics                            |  |
|             | Thermodynamics                         | Engineering Graphics                            | Thermodynamics                               | Engineering Graphics                            | Thermodynamics                                  |  |
|             | Dynamics                               | Thermodynamics                                  | Statics                                      | Statics   | Statics   |  |
|             | Machine Dynamics                       | Measurements and Instrumentation                | Dynamics                                     | Mechanics of Materials                          | Dynamics  |  |
|             | Model Analysis of Dynamic Systems      | Engineering Analysis for Mech.                  | Kinematics and Dynamics of Machinery         | Thermodynamics                                  | Computer Applications in Mechanical Engineering |  |
|             | Machine Design                         | Dynamics  | Fluid Mechanics                              | Dynamics  | Machine Design                                  |  |
|             | Heat Transfer                          | Materials and Manufacturing Selection in Design | Machine Design                               | Machine Design                                  | Fluid Mechanics                                 |  |
|             | Fluid Mechanics                        | Fluid Mechanics                                 | Control of Mechanical Systems                | Fluid Mechanics                                 | Control of Mechanical Systems                   |  |
|             | Measurements and Instrumentation       | Heat Transfer                                   | Measurements and Instrumentation             | Control of Mechanical Systems                   | Measurements and Instrumentation                |  |
|             | Mechanical Engineering Systems         | Control of Mechanical Systems                   | Manufacturing Methods and Processes          | Heat Transfer                                   | Heat Transfer                                   |  |
|             | Control of Mechanical Systems          | Machine Design                                  | Heat Transfer                                | Measurements and Instrumentation                | Interdisciplinary Industrial Design Projects    |  |
|             | Fourth Year                            | Interdisciplinary Industrial Design Projects    | Interdisciplinary Industrial Design Projects | Interdisciplinary Industrial Design Projects    | Interdisciplinary Industrial Design Projects    |  |

## Introduction to Mechanical Engineering

Course Catalog Description: *Introduction to the mechanical engineering curriculum and profession. Orientation for successful transition of new students to college life. Engineering approach to problem solving and computer use in all areas of mechanical engineering. Exchange of information regarding academic, technical, social, ethical, and professional matters between students, faculty, and practicing professionals*<sup>29</sup>.

Introduction to Mechanical Engineering is the curriculum cornerstone class taught mainly to first-year students. In this course, students study fundamental concepts of mechanical engineering such as mechanical advantage and energy conversion. Very broadly, students learn how latent energy can be turned into useful work by using simple machines. As this will be the initial implementation of the steam engine as a fundamental learning object, students will study the history of steam engines and their basic function. To enforce the notion that the design process is an iterative process, students can research how steam engines have evolved through the years. As done by Rowan University, students should be encouraged to design their own steam engine and participate in a friendly competition<sup>4</sup>. Students can use their creativity in a controlled learning environment.



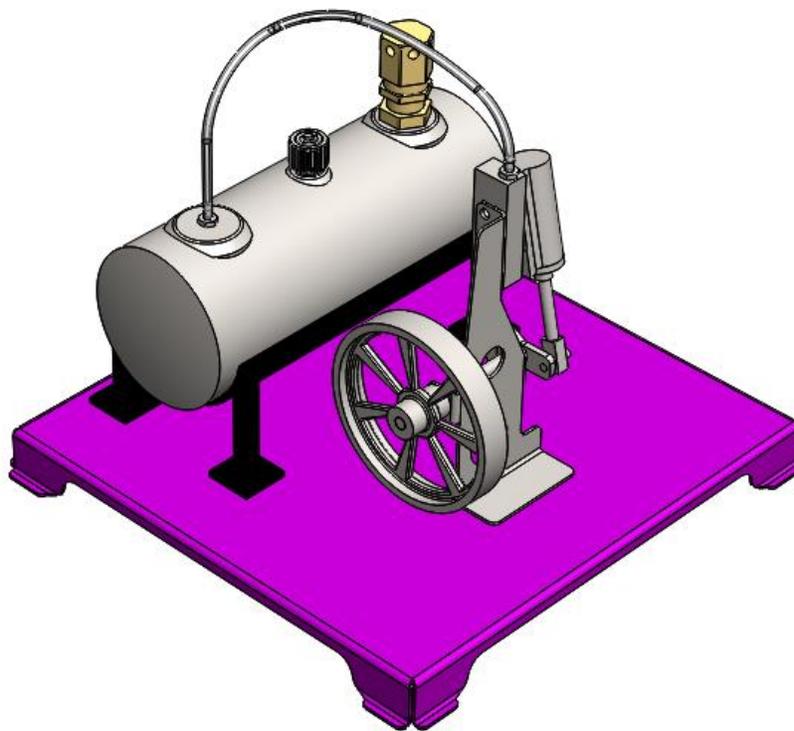
**Figure 10: Concept of Simple Machine**

This course does not have any mechanical engineering prerequisites. Thus, students are not required to rely on any previous engineering knowledge they may have.

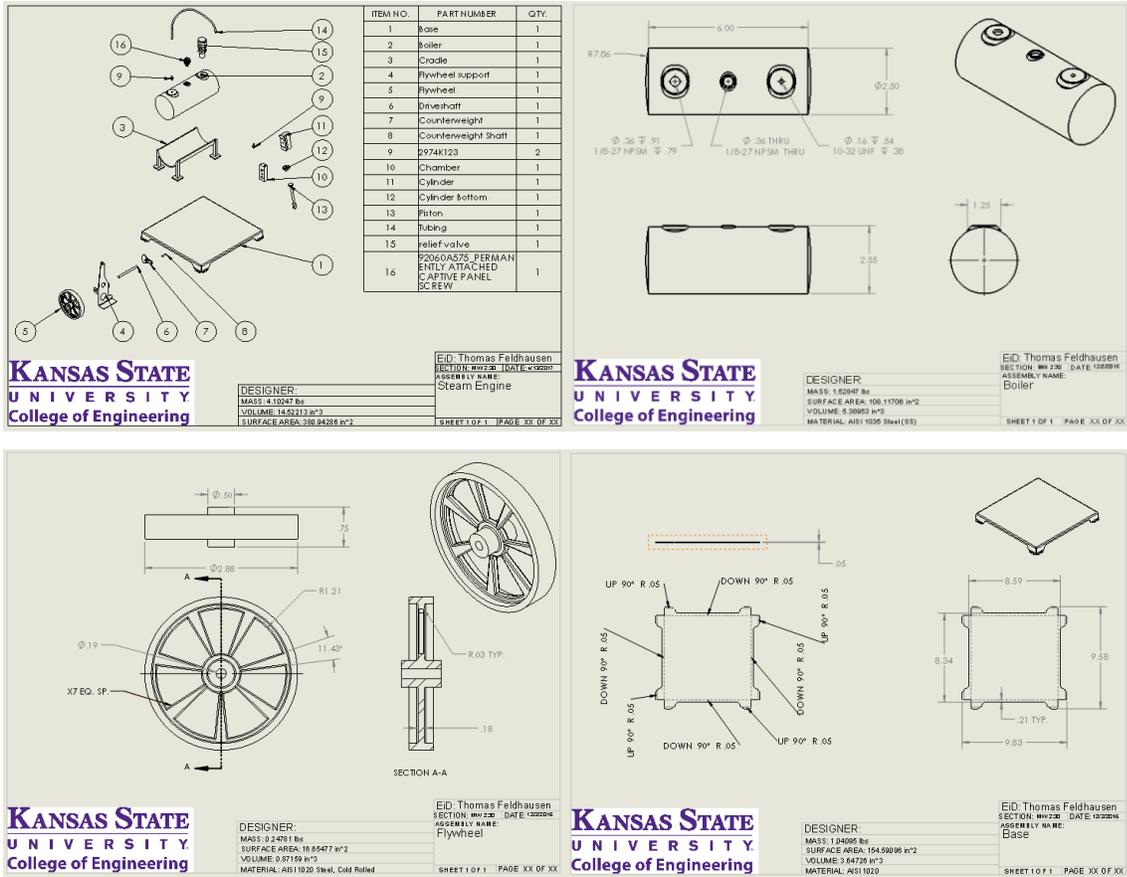
## Engineering Graphics

Course Catalog Description: *Technical sketching, study of basic principles of projective geometry, multiview drawings, pictorials, reading and interpreting drawings, introduction to CAD, sectioning, dimensioning*<sup>29</sup>.

Engineering Graphics develops visualization skills that are critical for communication. Students study hand drafting and a computer-aided design (CAD) program. After conceptually designing their own steam engines in the Introduction to Mechanical Engineering course, students will be ready to create a physical design. Working in teams, students will be given a sample steam engine to disassemble, measure, and model. This concept is similar to courses implemented at Stanford University<sup>13</sup> and Tuskegee University<sup>18</sup> as previously discussed. Examples of a CAD model and associated drawings are shown in Figures 11 and 12.



**Figure 11: CAD Model of Steam Engine**



**Figure 12: Various Steam Engine Technical Drawings**

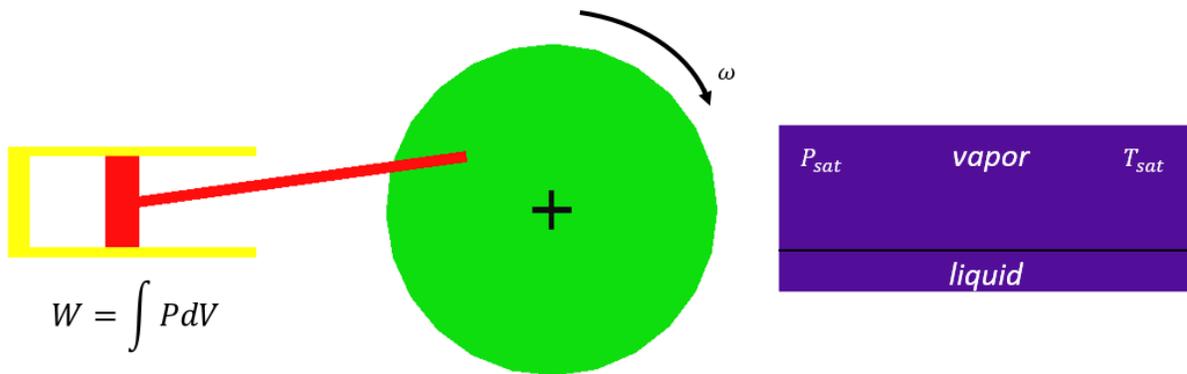
Through this process, the students will have hands-on experience with the physical device and a working knowledge of how it functions. Upon completion of a CAD model of the physical learning object, they can be guided through the process of 3D printing their own functional steam engine.

This course does not have any mechanical engineering prerequisites. Thus, students are not required to rely on any previous engineering knowledge they may have.

## Thermodynamics

Course Catalog Description: *Properties of the pure substance. The first and second laws of thermodynamics. Gas mixtures and psychrometry*<sup>29</sup>.

Thermodynamics develops an understanding of energy conversion from heat to work. Students study how the expansion of a gas can create mechanical work. The piston-cylinder assembly of the steam engine will demonstrate this concept. The students' familiarity with the specific components will give them a physical object they can analyze, thus deepening their understanding of thermodynamics.



**Figure 13: Thermodynamics of FLIP**

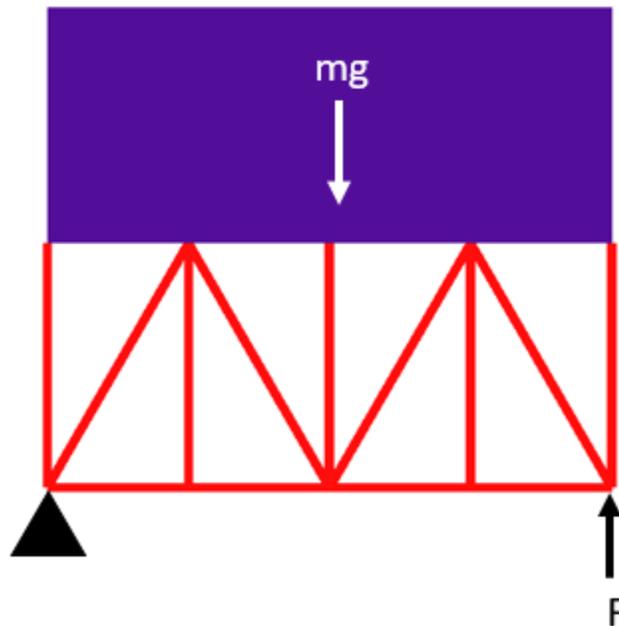
This course does not have any mechanical engineering prerequisites. Thus, students are not required to rely on any previous engineering knowledge they may have.

## Statics

Course Catalog: *Composition and resolution of forces; equilibrium of force systems; application of general laws of statics to engineering problems, including use of vector algebra, friction and force analyses of simple structures, cables, and machine elements; center of gravity; moments of inertia<sup>29</sup>.*

Statics develops an understanding of methods to analyze reaction forces on engineering systems. Students study the forces associated with static engineering systems. A truss structure supporting the boiler of the steam engine will demonstrate this concept. The students' familiarity with the boiler will give them a physical object they can analyze, thus enhancing their understanding of statics.

This course does not have any mechanical engineering prerequisites. Thus, students are not required to rely on any previous engineering knowledge they may have.



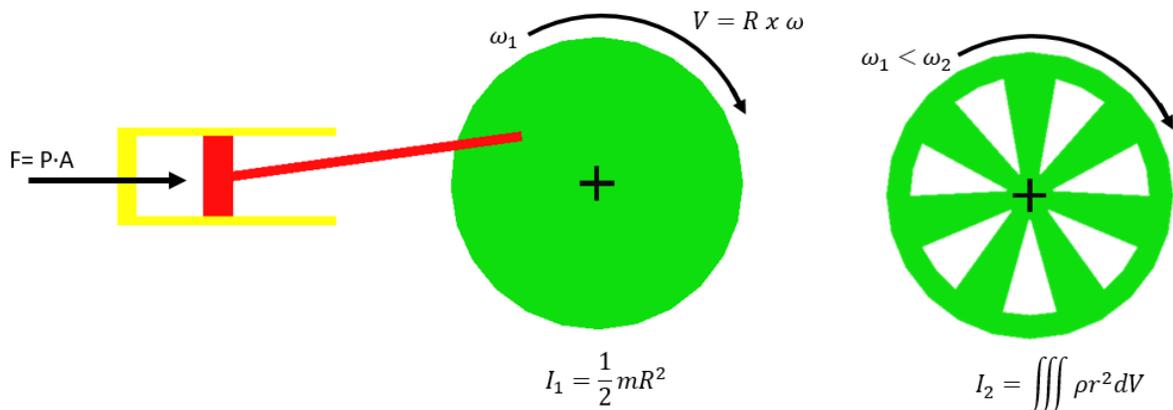
**Figure 14: Force Diagram of FLIP**

## Dynamics

Course Catalog: *Vector treatment of kinematics, Newton's laws, work and energy, impulse and momentum, with applications to problems of particle and rigid body motion*<sup>29</sup>.

Dynamics develops an understanding of kinematic concepts such as angular momentum. Students study how geometry changes affect the angular momentum of objects. Students can demonstrate this concept by designing and experimenting with different types of flywheel geometry. Being able to relate to the piston-cylinder assembly will give the students a physical object to analyze, thus enhancing their understanding of dynamics.

Statics is a prerequisite to Dynamics. Thus, students will be able to rely on their knowledge of force diagrams. In particular, the force diagram of the steam engine piston-cylinder.

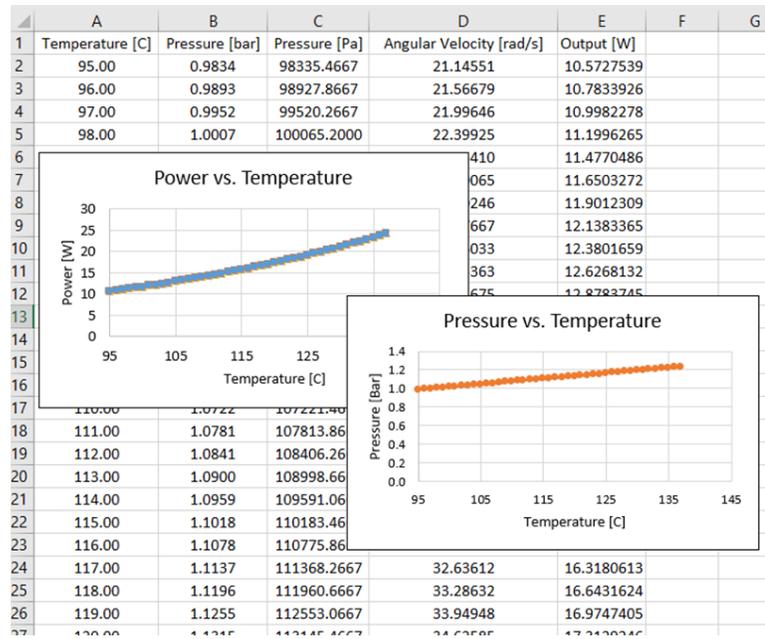


**Figure 15: Dynamics Diagram of FLIP**

## Computer Applications in Mechanical Engineering

Course Catalog Description: *The development and application of computer techniques to the problems of design and analysis in mechanical engineering, including computer programming (abstraction and problem solving; algorithms; control structures; input/output; functions; arrays and array processing)*<sup>20</sup>.

Computer Applications in Mechanical Engineering develops an understanding of computer programming. Students study how data can be analyzed and interpreted with the use of computer automation. Students can demonstrate this concept by analyzing data recorded from an operating steam engine. As previously implemented by researchers at Miami University, students who related theoretical data to experimental data had increased critical thinking abilities.<sup>21</sup> The students' familiarity with the specific components of the steam engine will help ease their understanding of the material in Computer Applications in Mechanical Engineering.



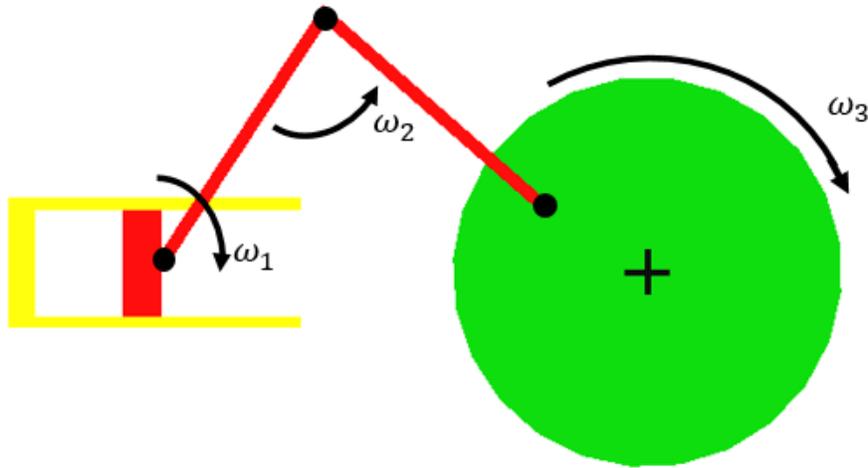
**Figure 16: Example Computer Applications Data of FLIP**

This course does not have any mechanical engineering prerequisites. Thus, students are not required to rely on any previous engineering knowledge they may have.

## Machine Design

Course Catalog Description: *Introduction to the design and analysis of machine elements. Emphasis on materials, loads, stress, strain, deflection, failure theories, and finite element analysis. Applications include design and analysis of shafts, gears, and fasteners, weldments, springs, bearings*<sup>29</sup>.

Machine Design develops an understanding of different types of mechanical mechanisms. Students study how multiple linkages can be used in a particular mechanism. Students can demonstrate this concept by designing different linkages to be used between the piston and flywheel. A similar course that utilized a steam engine at Rowan University<sup>4</sup> showed that hands on learning can result in students feeling an increase in their knowledge of course fundamentals. The students' familiarity with piston-cylinder and flywheel assembly will give them a physical object they can study and structure their machine design knowledge around.



**Figure 17: 2 Bar Linkage Diagram of FLIP**

Engineering Graphics and Dynamics are both prerequisites of Machine Design. Thus, Machine design can rely on knowledge obtained from both Engineering Graphics and Dynamics.

## **Measurement and Instrumentation Laboratory**

Course Catalog Description: *Theory and application of mechanical engineering measurements, instrumentation, and computer-based data acquisition*<sup>29</sup>.

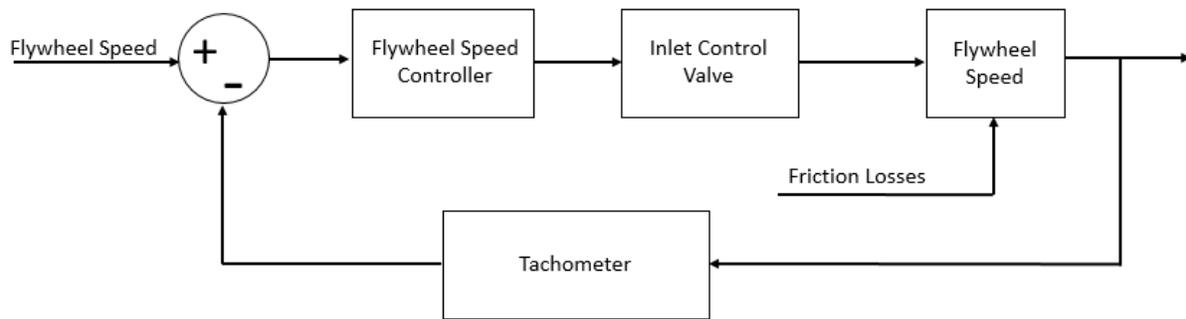
Measurement and Instrumentation Laboratory develops an understanding of different measurement devices and techniques. Students study how there is uncertainty associated with every measurement device. Students can demonstrate this concept by experimenting with different temperature measuring devices on the boiler. Further experiments can be done on measuring the angular velocity of the flywheel. The students' familiarity with the boiler and flywheel will give them physical objects they can analyze, thus supplementing student outcomes of Measurement and Instrumentation Laboratory.

Thermodynamics is a prerequisite to Measurement and Instrumentation Laboratory. As a result, experiments involving thermometers can be easily implemented with students having a fundamental knowledge of thermodynamic properties.

## Control of Mechanical Systems

Course Catalog Description: *Introduction to modeling and control of dynamic systems encountered by mechanical engineers. Topics include basic linear systems modeling and analysis; feedback control; time response and stability of dynamic systems; introduction to root locus and frequency response design*<sup>29</sup>.

Control of Mechanical Systems develops an understanding of controlling a dynamic system. Students study how to model a control loop diagram. Students can demonstrate this concept by creating a model to control the speed of the flywheel. The students' familiarity with the specific components of the steam engine ease students' learning of Control of Mechanical Systems.



**Figure 18: Flywheel Speed Control Loop of FLIP**

Dynamics, Computer Applications in Mechanical Engineering, and Measurement and Instrumentation Laboratory are all prerequisites to Control of Mechanical Systems.

## **Fluid Mechanics**

Course Catalog Description: *Physical properties; fluid statics; dynamics of ideal and real fluids (for incompressible and compressible flow); impulse and momentum; laws of similitude; dimensional analysis; flow in pipes; flow in open channels; flow about immersed objects<sup>29</sup>.*

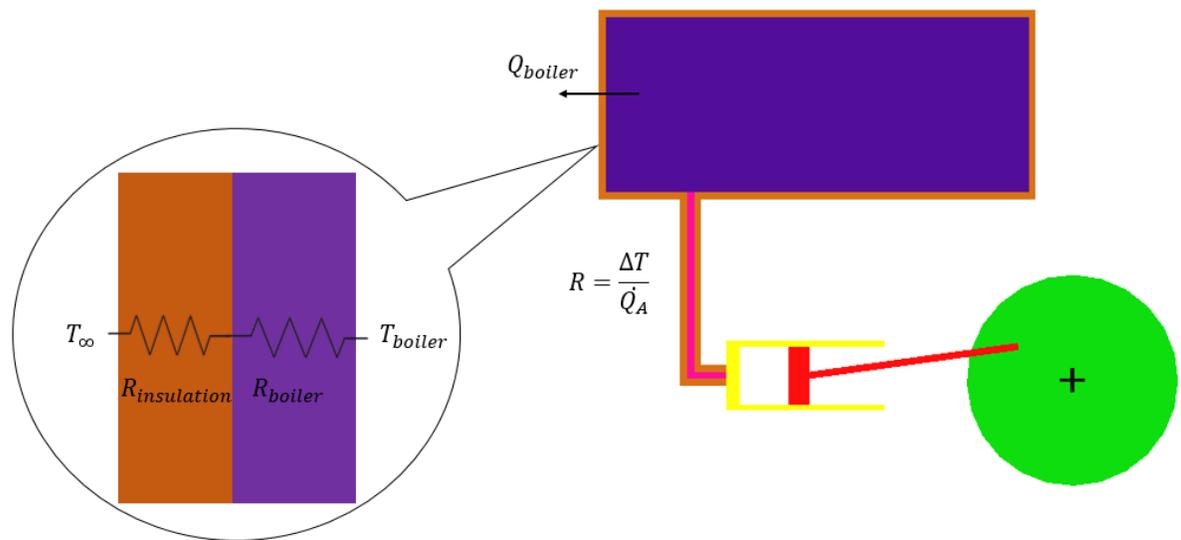
Fluid Mechanics develops an understanding of fluid flow, especially in pipes. Students study how pressure loss in pipes is due to fluid friction. Students can demonstrate this concept by experimentally measuring the pressure loss between the boiler and the piston-cylinder. Further implementation of the steam engine could include studying how compressed air flows through the adapter valve of the steam engine. Students' ability to analyze the steam engine will give them a familiar object to help deepen their understanding of fluid mechanics.

Dynamics and Thermodynamics are both prerequisites to Fluid Mechanics. This requires students to have a basic understanding of fluid properties and simple energy principles.

## Heat Transfer

Course Catalog Description: *Fundamentals of conduction, convection, and radiation; principles of heat exchanger design and dimensional analysis*<sup>29</sup>.

Heat Transfer develops an understanding of the different modes of heat transfer. Students study how heat is lost through conduction, convection, and radiation. Students can demonstrate this concept by experimenting with the addition of insulation around the boiler. Students' ability to analyze the heat loss of the steam engine will help deepen their understanding of heat transfer.



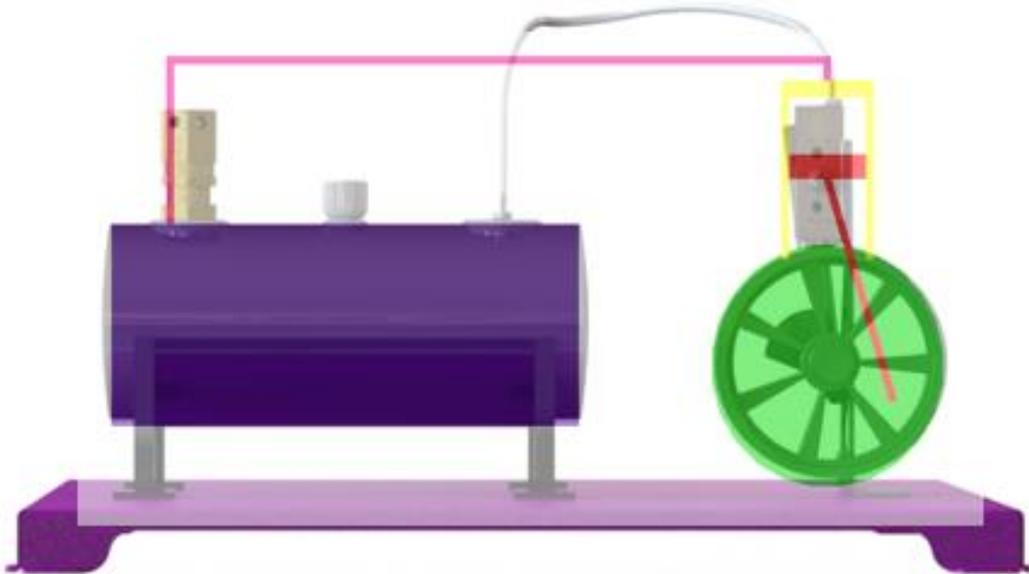
**Figure 19: Thermal Resistor Diagram of FLIP**

Computer Applications in Mechanical Engineering and Fluid Dynamics are both prerequisites to Heat Transfer.

## Interdisciplinary Industrial Design Projects

Course Catalog Description: *Introduction to design theory, project management, team dynamics and socio-economic context of design, etc.; application of design principles, engineering analysis and experimental methods to an industrial interdisciplinary design project involving design, analysis, fabrication and testing*<sup>29</sup>.

Interdisciplinary Industrial Design Projects is the capstone course of the mechanical engineering curriculum. Students study design theory while also learning the basics of project management. Students can demonstrate this by designing a new steam engine to be manufactured. The students' familiarity with each specific steam engine component will help enhance their knowledge and understanding of the engineering design process.



**Figure 20: Steam Engine Integration**

Machine Design, Measurements and Instrumentation Laboratory, Fluid Mechanics, and Heat Transfer are all prerequisites to Interdisciplinary Industrial Design Projects.

It has been shown that the FLIP is applicable and can be implemented into each course in a mechanical engineering curriculum. Guided from previous research, the FLIP relies on course integration, physical objects, and student engagement to enhance a mechanical engineering curriculum. As a result, students in any course will be able to identify and relate to content and concepts taught in any other mechanical engineering course.

### **Non-Traditional Curriculum Progression**

In this thesis, courses were discussed in sequential order as identified by the Kansas State University Mechanical Engineering curriculum. Although, students may not follow this course sequence as previously laid out. To mitigate issues of students that do not follow the curriculum sequentially, instructors must rely only on knowledge from prerequisite courses. For example, some curriculums require students to take the Engineering Graphics and Dynamics courses before they can take the Machine Design course. Thus, the Machine Design instructor can only rely on those courses when implementing the FLIP. Adhering to these restrictions will reduce the confusion of students who are not in mechanical engineering and unfamiliar with the FLIP.

### **Enhanced Curricula Warnings**

Although enhanced curricula generally result in positive outcomes, this section outlines disadvantages and warnings associated with such curriculum enhancements that have been identified by the literature.

The FLIP is guided and built from previous research. Much of the literature doesn't discuss issues associated with integrated curricula, yet, Everett discusses issues associated with an integrated program implemented at Texas A&M. An important factor faced with their implementation plan was the increased cost of an integrated curriculum<sup>30</sup>. Increased planning time, faculty load and teaching assistance all led to a rise in curriculum cost. Furthermore, it was discussed how difficult reaching a consensus on curriculum matters in a single department was<sup>30</sup>. Further research of course integrations at Texas A&M University observed that though student attitudes improved for the value of homework and lifelong learning, their overall evaluation of engineering decreased<sup>12</sup>. Problems of teamwork, grading practices, student complaints, and nonfunctional teams all required faculty attention<sup>12</sup>. This research integrated five courses together which led to faculty meeting once a week to develop and recalibrate the program to keep each course at the same threshold. This was described as unsettling and confusing for

students and teachers alike<sup>12</sup>. It can be concluded from these previous enhanced curricula that curricula changes must have a strong foundation to alleviate pressure from the involved faculty.

In each research scenario discussed in this thesis, it is clear that a great deal of time must be devoted to any curriculum change, regardless of the magnitude. Curriculum changes are often developed over the summer when professors have more time away from teaching<sup>31</sup>. Lack of prior experience and research with such integrated curricula is one determining factor of success<sup>12,32</sup>. The FLIP was developed to help mitigate these issues. With a well-rounded implementation strategy, the FLIP can be implemented without immense time contributions from faculty and reduced funding from the institution.

Though the given examples of FLIP implementation are not comprehensive, this thesis gives a synopsis of how the steam engine can be implemented into a typical Mechanical Engineering curriculum. Some implementations are intended to be design modifications for the steam engine while others are quests for understanding. Yet, all involve learning more about the physics of the object and result in deeper understanding. As the usage of a FLIP matures in a curriculum, instructors will find new and inventive ways to implement it into their respective courses. To ensure this curriculum is advantageous to students, great care must be taken when evaluating the FLIP.

## Chapter 5 - Assessment of FLIP Implementation

Research that has been previously discussed in this thesis that was used to guide the development of the FLIP will also guide the assessment methods of the FLIP. Since the FLIP is built and guided from previous research, potential assessment methods will also be determined from previous research. The methodology of utilizing the assessment tools of similar programs will help quickly and reliably determine the effectiveness of the FLIP.

During the literature review process of this thesis, it was noticed that many of the research scenarios that were identified did not discuss their assessment plan, or their outcomes<sup>6</sup>. Methods are often generically outlined and results will be paraphrased or omitted entirely. In a paper on integrated engineering curricula, Froyd states that “No program has articulated learning outcomes and assessment processes associated with how well students are making connections<sup>6</sup>”. A critical step in developing integrated curricula is translating statements about the importance of integration into outcomes and assessment methods<sup>6</sup>. For the FLIP to hold any validity, a strong assessment method must be constructed.

### Programs Using Survey Assessment Methods

Surveys are overwhelmingly the most popular form of assessment. Research states that surveys will be used to gather student attitudes towards a curriculum change, yet many of them are not discussed in detail. Surveys that are discussed in detail have been outlined.

To determine the effectiveness of the steam engine in the Thermodynamics and Mechanical Design course integrations at Rowan University, a survey using a Likert scale was implemented<sup>4</sup>. A similar survey was also used for the embedded learning modules at Miami University. Here, students as well as external faculty participated in the course survey. A Likert scale survey was also collected at the Colorado School of Mines to assess a first-year integration program called *connections*<sup>10</sup>. Here, the survey focused on student attitudes towards the integrated program. Since the FLIP utilizes elements from many programs that use Likert scales, the FLIP should also include similar surveys. Examples of possible Likert scale survey questions are shown in Table 3.

**Table 3: FLIP Likert Scale Example Questions**

| <b>Please indicate how strongly you agree or disagree with each statement</b>   |       |          |                   |
|---|-------|----------|-------------------|
| <b>1. The FLIP helped to increase my teamwork skills in this course.</b>  |       |          |                   |
| Strongly Agree  | Agree | Disagree | Strongly Disagree |
| <b>2. The FLIP provided the opportunity to learn and apply new concepts (i.e. Experimental and/or Computational).</b>                     |       |          |                   |
| Strongly Agree  | Agree | Disagree | Strongly Disagree |
| <b>3. The FLIP required extensive use of knowledge from earlier courses in this course (i.e. Material Science, Machine Design, etc.).</b> |       |          |                   |
| Strongly Agree  | Agree | Disagree | Strongly Disagree |

Instead of using a Likert scale survey, other researchers implemented an informal survey such as a verbal survey that was implemented in the dissection course taught at Stanford University. This course was evaluated through periodic discussions with students<sup>13</sup>. Students are able to give feedback regarding what they like, and thoughts about how the course can be made better. Similarly, the hands-on laboratories where students “feel” concepts at the University of Tennessee are directly measured by asking students a series of questions related to the concepts taught in class and demonstrated in the laboratory<sup>14</sup>. These mid-course pseudo-surveys resulted in real-time feedback that allowed these programs to make mid-course corrections. This method will be useful to implement with the FLIP, so slight changes can be quickly made rather than waiting until the formal assessment surveys at the end of the semester.

### **Programs Assessing Retention/Graduation Rates**

Likert scale surveys as well as other surveys can be unreliable without proper development and testing<sup>33</sup>. Central tendency bias where participants avoid extreme response categories, or acquiescence bias where participants agree with statements in order to “please” the experimenter are both drawbacks to using Likert scale surveys<sup>34</sup>. A different approach to assessment in a curriculum implementation is looking at retention and graduation rates of participating students.

The enhanced curriculum at Worcester Polytechnic Institute for Chemical engineering looked at retention rates of first year students. It was concluded that less than 10% of the test group changed majors during the first-year while about 20% of the control group changed

majors<sup>22</sup>. Other programs assess retention rates of students by categorizing students by ethnicity such as the Foundation Coalition (FC) program at Texas A&M University.

For a longitudinal study, graduation rates will need to be assessed. Increased graduation rates were seen at the Colorado School of Mines due to a first-year integration program called *connections*<sup>10</sup>. The FLIP is intended to be implemented through an entire mechanical engineering curriculum. Thus, graduation rates of students should be assessed and compared to legacy rates to determine how many students complete a mechanical engineering program, rather than measuring first-and second-year retention rates

With the use of the FLIP, we hope to not only see more students retained in engineering, but we hope to see students do better in engineering. To assess this, the course pass rates of students may be an important assessment tool. This was done with the integrated curriculum at North Carolina State University. They reported that the pass rate for the participating students (69%) was higher than the control group (52%)<sup>9</sup>.

It has been shown that retention and graduation rates can be used to give a reliable and repeatable assessment of the FLIP that is not affected by student attitudes towards a curriculum. Both values can be easily compared to legacy graduation rates collected by each institution. With the implementation of the FLIP, we hope to see an increase in both quantitative values. This increase will show that the FLIP is effective in retaining and graduating more students from a mechanical engineering institution.

## **ABET**

Mechanical engineering programs strive to be accredited by the Accreditation Board for Engineering and Technology (ABET)<sup>35</sup>. ABET emphasizes the objectives and goals that are required for an engineering curriculum to meet the outcomes desired by industry. As a result, ABET is a driving factor when determining the direction of enhanced curricula<sup>35</sup>. Thus, it is desirable for major curriculum changes to align with ABET criteria<sup>35</sup>.

The curriculum criteria for mechanical engineering from ABET states: “*The curriculum must require students to apply principles of engineering, basic science, and mathematics (including multivariate calculus and differential equations); to model, analyze, design, and realize physical systems, components or processes; and prepare students to work professionally in either thermal or mechanical systems while requiring topics in each area*<sup>36</sup>.” It has been shown in the Curriculum Implementation chapter that the FLIP encompasses each of these

curriculum attributes. This increases the attractiveness of implemented the FLIP since it aligns with ABET criteria. Furthermore, ABET can be used to assess the FLIP. Occurring every six years, ABET is an external method that can be regularly used to assess the FLIP.

In addition to assessing the curriculum, ABET also identifies eleven student outcomes that each student must attain before graduation<sup>36</sup>. The FLIP can be used to attain each of these outcomes. The ABET student outcomes are<sup>36</sup>:

- a) an ability to apply knowledge of mathematics, science, and engineering
  - i. Knowledge of mathematics, science, and engineering can be used to describe FLIP concepts.
- b) an ability to design and conduct experiments, as well as to analyze and interpret data
  - i. As shown in the course integrations, there are multiple opportunities for experiments to be conducted on the FLIP.
- c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
  - i. Specific components of the FLIP can be designed by students while having them adhere to the specified realistic constraints.
- d) an ability to function on multidisciplinary teams
  - i. Similar to the study done at Roemer University, students can work on multidisciplinary teams to optimize the design of the FLIP.
- e) an ability to identify, formulate, and solve engineering problems
  - i. Students can describe the physics of the FLIP by using their engineering problem solving skills.
- f) an understanding of professional and ethical responsibility
  - i. When designing new FLIP components, students should assess the safety aspect of each design, especially with moving or hot components.
- g) an ability to communicate effectively
  - i. The instructor may choose to implement the FLIP in such a way that requires students to work in groups. When working with the FLIP as a group, students will have to communicate their ideas effectively.

- h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
  - i. FLIPs such as the steam engine can be addressed in a larger frame of reference. Such as how steam engines were an integral part of the industrial revolution.
- i) a recognition of the need for, and an ability to engage in life-long learning
  - i. Interacting with the FLIP through their whole academic career will show students how knowledge is continually built upon itself.
- j) a knowledge of contemporary issues
  - i. Students can be encouraged to devise a plan for how the FLIP can be used to solve a real-world problem. For example, using a steam engine to pump water in a third-world country.
- k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.
  - i. Students can achieve this by utilizing computer aided design programs to enhance components of the FLIP.

It has been shown that the FLIP can be used to address each of the ABET outcomes. Hence, mechanical engineering programs can utilize the FLIP to help accomplish these outcomes and achieve ABET accreditation. In turn, the FLIP can be assessed and critiqued by means of ABET assessment outcomes.

### **Fundamental Learning Integration Platform Effectiveness**

Some programs also outline multiple methods that they use to assess their curriculum implementations. Instead of just looking at one direct outcome, these give a well-rounded aspect of an entire curriculum. The FLIP should utilize a similar approach to assess its effectiveness. Higher retention rates, increased critical thinking ability, and increased student engagement, are all direct outcomes of the FLIP, but other unintended outcomes may also be observed. Thus, a strong assessment plan must encompass all of the outcomes. The use of various assessment methods are seen at Ohio State University<sup>37</sup> and the University of Colorado at Boulder<sup>2</sup>. Various assessment methods to evaluate the effectiveness of the FLIP are:

1. Retention rates of first-through fourth-year students

- a. This method will assess the retention and graduation rates of an enhanced mechanical engineering curriculum that utilized the FLIP. Legacy rates should also be used to create a baseline for comparison.
2. Critical thinking abilities of students
  - a. The use of integrated homework and exam problems will test students' ability to apply their enduring knowledge and common sense to solve integrated problems. With the use of a grading rubric, the collection of the student scores will give a cross-sectional view of students' critical thinking abilities. If a control group is available, scores should be compared between the two curricula.
3. Student Engagement
  - a. Student surveys will be used to analyze student engagement. These surveys will collect student perspectives and attitudes regarding the FLIP, examples used in class, and the course in general. Surveys will also be implemented to assess whether or not faculty see a change in student engagement in the classroom.
4. Comparison of Fundamental of Engineering (FE) pass rates to legacy pass rates
  - a. This method will assess whether the FLIP results in an increase in pass rates of the FE exam. This should be done over multiple semesters, and/or compared to legacy data if available.
5. Overall GPA of students categorized by year
  - a. This method assesses the GPA of mechanical engineering students and is categorized by year. The implementation of the FLIP may result in an increase if measured over multiple semesters and compared to legacy data if available.
6. Participation in co-op and internship programs
  - a. The hands-on learning practices of the FLIP may result in an increase in self-efficacy towards entering the industry. Thus, student will be more likely to participate in the co-op and internship programs.
7. Focus groups of industry experts

- a. Using industry experts to keep FLIP relevant to industry. This will help enhance the FLIP and better prepare students for industry.

There are many methods in use to assess the validity and successfulness of curricula implementations. The majority of the programs collect and analyze student and faculty feelings to look at the perceptions of the implemented program through the use of surveys. Others take a numerical approach by collecting retention and graduation rates of students. Some implement a variety of assessment methods to create a well-rounded picture. Utilizing assessment methods identified in relevant research, the FLIP will utilize various assessment methods that will directly measure the desired outcomes and determine the effectiveness of the FLIP.

## Chapter 6 - Conclusion

Throughout an engineering curriculum, there should be a realistic and practical connection between courses, such that each course is not represented as an individual silo of knowledge<sup>1</sup>. To retain such knowledge, studies have shown that students need to make connections between a new word or image and existing knowledge to remember it<sup>6</sup>. Before either of these issues can be mitigated, students must also be engaged in the learning process<sup>19</sup>. To address each of these issues, literature was reviewed to develop a solution for courses taught in a typical mechanical engineering department.

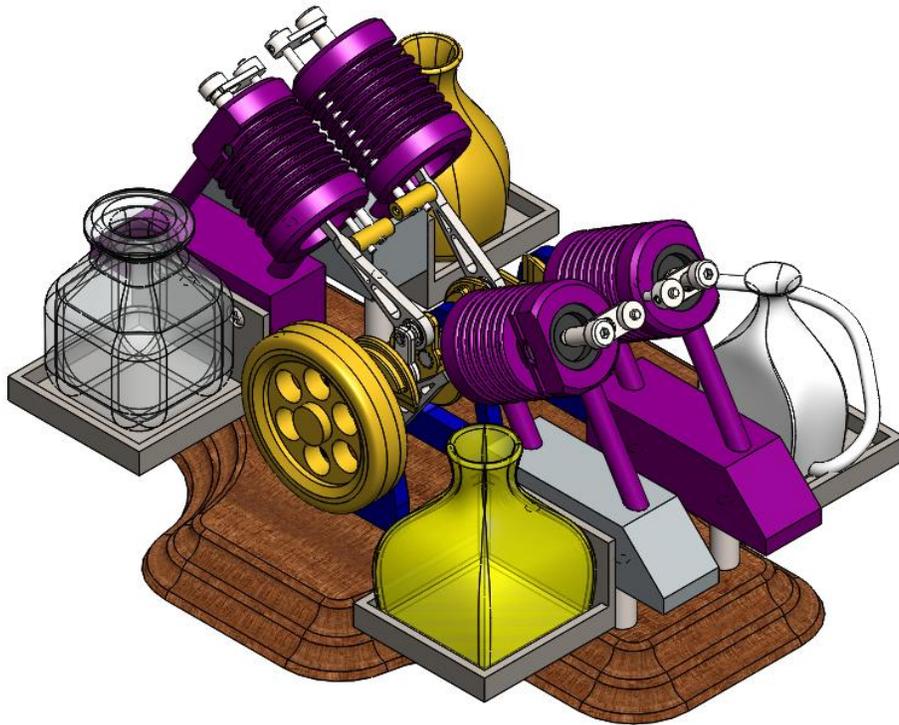
This thesis proposes a hands-on learning object that can ubiquitously connect courses throughout a mechanical engineering curriculum. Termed as the Fundamental Learning Integration Platform (FLIP), the entire curriculum will be centered around and built upon it. Building upon previous research on course integration, hands-on learning, and student engagement, the FLIP will integrate each course in a mechanical engineering curriculum. It will create a physical connection between theoretical and practical engineering concepts while actively engaging each student in the learning process. Higher retention rates, increased passing rates of the Fundamentals of Engineering exam, and increased student inclusion in the classroom will all be a desired result of the implementation of the FLIP. The FLIP has also been shown to align with ABET curriculum criteria, which is a driving factor in many mechanical engineering curricula.

The results of this FLIP curriculum will be used to help move towards a fully integrated curriculum in mechanical engineering, benefiting both students and educational institutions through applied, hands-on learning.

## Chapter 7 - Future Work

To help keep the curriculum fresh and interesting for the students and faculty, multiple FLIPs should be developed. With the development of multiple FLIPs, each course could utilize multiple physical objects each semester. This could result in students graduating with not only a diverse knowledge of the steam engine, but of multiple FLIPs. The challenge will be finding more ubiquitous objects that are applicable to all courses in a curriculum while capturing every student's interest.

One example may be a stirling engine as shown below. Students can look at the basic design of the stirling engine in the Introduction to Mechanical Engineering course, design it in Engineering Graphics and experiment with it in Dynamics and Machine Design.



**Figure 21: Potential FLIP Object – Stirling Engine**

With more research, the feasibility of implementing the FLIP outside of mechanical engineering could be assessed. With institutional support, platforms such as the steam engine could potentially be integrated throughout an entire engineering college. Real-world engineering is inter-disciplinary, so engineering education should be interdisciplinary as well. Different engineering majors should collaborate throughout a curriculum. Engineering students from

mechanical, electrical, chemical, industrial, and other majors should all interface with each other throughout their college careers.

Furthermore, the idea of implementing FLIP on the university scale should also be assessed. Students should see the importance and connection to their career from any course that they take while at a university. It may be feasible that the FLIP could not only enhance a mechanical engineering curriculum, but the curriculum of an entire university.

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