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Modifying a Junior Year Machine Design Project to Break Down Knowledge Silos in the Mechanical Engineering Curriculum

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Scott Kiefer has spent the past twenty-one years teaching mechanical engineering at four different colleges. He started at the University of Puerto Rico at Mayaguez in the traditional role of teaching and administering a modest graduate research program. At Trine University, a small private school in Angola, Indiana, he focused on undergraduate education while teaching ten different courses ranging from introductory freshman courses to senior capstone. Scott also served as an advisor to many different undergraduate research projects. He then moved on to Michigan State University and took a position as a teaching specialist concentrating on undergraduate classroom instruction. Scott finally settled at York College of Pennsylvania. He has been at York College for over ten years and feels as if he has found a place where the focus on teaching and students aligns well with his background and interests.

Dr. Stephen Andrew Wilkerson, P.E., York College of Pennsylvania

Stephen Wilkerson (swilkerson@ycp.edu) received his PhD from Johns Hopkins University in 1990 in Mechanical Engineering. His Thesis and initial work was on underwater explosion bubble dynamics and ship and submarine whipping. After graduation he took a position with the US Army where he has been ever since. For the first decade with the Army he worked on notable programs to include the M829A1 and A2 that were first of a kind composite saboted munition. His travels have taken him to Los Alamos where he worked on modeling the transient dynamic attributes of Kinetic Energy munitions during initial launch. Afterwards he was selected for the exchange scientist program and spent a summer working for DASA Aerospace in Wedel, Germany 1993. His initial research also made a major contribution to the M1A1 barrel reshape initiative that began in 1995. Shortly afterwards he was selected for a 1 year appointment to the United States Military Academy West Point where he taught Mathematics. Following these accomplishments he worked on the SADARM fire and forget projectile that was finally used in the second gulf war. Since that time, circa 2002, his studies have focused on unmanned systems both air and ground. His team deployed a bomb finding robot named the LynchBot to Iraq late in 2004 and then again in 2006 deployed about a dozen more improved LynchBots to Iraq. His team also assisted in the deployment of 84 TACMAV systems in 2005. Around that time he volunteered as a science advisor and worked at the Rapid Equipping Force during the summer of 2005 where he was exposed to a number of unmanned systems technologies. His initial group composed of about 6 S&T grew to nearly 30 between 2003 and 2010 as he transitioned from a Branch head to an acting Division Chief. In 2010-2012 he again was selected to teach Mathematics at the United States Military Academy West Point. Upon returning to ARL's Vehicle Technology Directorate from West Point he has continued his research on unmanned systems under ARL's Campaign for Maneuver as the Associate Director of Special Programs. Throughout his career he has continued to teach at a variety of colleges and universities. For the last 4 years he has been a part time instructor and collaborator with researchers at the University of Maryland Baltimore County (http://me.umbc.edu/directory/). He is currently an Assistant Professor at York College PA.

Modifying a junior year machine design project to break down knowledge silos in the mechanical engineering curriculum

Abstract

A common feature of Mechanical Engineering curriculum is an integrated Capstone project where students must combine knowledge from various courses to complete a design within a team. However, in many curricula, this culminating project is the first time students are forced to break down the silos that separate thermal-fluid sciences, electronic integration and solid mechanics. Most real-world problems involve an intersection of at least two of these disciplines, which means that having additional practice in systems level, integrated thinking will better prepare our graduates to take on complex engineering problems. We changed a standard machine design project (such as a walnut cracker or sawdust press) into a wind turbine design project. This new project integrates knowledge and components from three courses that are taken during the fall of junior year (Machine Design, Fluid Dynamics, and Instrumentation and Microprocessors) along with previous course work in Thermodynamics and solid modeling. Additionally, the project also requires students to learn 3D printing to create airfoils for their turbines which is becoming more and more important in many industrial sectors. We collected data on how students feel the integrated project impacted their understanding of the key course content.

Introduction

A challenge within all engineering curricula is broadening student perspective to see the interconnections beyond individual courses. This is because engineering curricula typically include courses that are, from the student perspective, self-contained. This self-containment is often unintentionally reinforced by faculty. A course on solid mechanics, for example, focuses on the principles and relationships from that discipline. There is little if any discussion of, say, thermodynamics or fluid mechanics in such a course, even though pumps have rotating shafts and pipes (and their bolted fittings) must be appropriately designed to withstand the operating pressure. This approach almost encourages students to place the different coursework into silos based on course numbers. While the fundamental content in each subdiscipline needs to be thoroughly covered in their own courses, it is not uncommon that areas for capitalizing on broader thinking and connection fall to the wayside.

Using projects within courses can help build bridges across these different subdisciplines if they are designed carefully. It is easy and common to design a course project that focuses on the topics within the course and does not require students to apply knowledge from several different courses. The first point where students are often required to make these cross-connections is the Capstone Design course. This is late in the curriculum, and allowing students to connect disciplines sooner would be beneficial for the students' professional development and for their Capstone experience.

There have been numerous reports from engineering departments on efforts to provide a platform for integration throughout their curriculum. Mitchell et. al. at University College London, restructured their entire curriculum to include single disciplinary and multi-disciplinary project-based learning (PBL) projects in each term [1]. While they did not report on the student response, they did highlight the level of buy-in that was needed across the engineering school and that numerous full-time teaching faculty were required to orchestrate the curriculum overhaul.

Other programs have instead tested the use of a single object or topic as a platform for integration. Gajic et. al. used a Mechatronics platform to integrate into course projects over the duration of the curriculum [2]. They focused on creating a Mechatronics kit that could grow with the students from their first-year through senior year, while still providing a firm foundation for continuity and connection. Alternatively, faculty at Kansas State integrated the curriculum through the discussion of a steam engine in every course in their curriculum, culminating in a steam engine Capstone build [3]. Traum et. al. attempted a pared down model of the steam engine integration that carried a rocketry project through five courses distributed throughout the curriculum instead of every course [4]. A benefit, but also hinderance, to these various longitudinal approaches is the need for multiple faculty to coordinate and maintain a trajectory for multiple years. This can be challenging in the event of load shifting, sabbaticals, or other disruptions. Another issue with the steam engine and rocketry integration models is that students and faculty may want to change the project after some time to provide variety. Given the level of integration, this would require a significant effort if modifications to the premise were required/desired.

There are also reports of integration through a single course or lab. Smaili et. al., used Mechatronics to integrate solid mechanics and electronic integration and control in a project-based setting [5]. Rossman et. al. instead used case studies to teach fluid mechanics and solid mechanics in an integrated introductory course to highlight the continuum between fluids and solids that exists in the real world [6]. While these are admirable, and require less coordination between faculty, they also do not have the same impact of truly integrating across the curriculum as they only focus on the cross-over between two sub-disciplines. Our program already included integration at a two-sub-discipline level in a few core courses and electives, so we wanted to try to integrate at least three sub-disciplines prior to the senior year.

Our goal was to investigate the impact of a targeted intervention to reduce silos between subdisciplines within a single semester. We designed a project that was explicitly part of both our Machine Design course and Fluid Mechanics laboratory, with necessary support from and integration of sensors developed in an Instrumentation Laboratory. The goal of the project was to allow students to connect principles from three disparate courses. We discuss the project and its impact on student views regarding the interconnection of the sub-disciplines of Mechanical Engineering.

Project Description

Students at York College of Pennsylvania take Machine Design, Fluid Mechanics, Instrumentation Laboratory and Thermo-Fluids Laboratory during the Fall semester of their junior year. At this time, students have already taken Thermodynamics and Mechatronics. Importantly, students are returning from their first mandatory Co-op experience during the summer between their sophomore and junior years. They are preparing for their second mandatory Co-op during the Spring semester of their junior year. This transition semester is an ideal time to give them project experience in the integration between sub-disciplines. The suggested course sequence for our students can be found in Appendix A.

The Machine Design course at York College has historically included a project component. These projects have typically required students to solely apply solid mechanics knowledge to arrive at a solution. Some example projects from recent years involve nutcrackers for Eastern black walnuts, presses to turn sawdust into pellets for a wood grill or stove, and devices to test the pressure exerted by tourniquets in use. While some electronics or instrumentation may enter these projects, there is little of the thermal-fluid sciences portion of Mechanical Engineering that appear in these challenges.

To create a project that more intentionally required students to think broadly across the Mechanical Engineering curriculum, we devised a project involving a wind turbine design. Students were to arrive at a design that could be placed on a structure at 150 feet in the air and were required to develop a prototype that could be tested in the low-speed wind tunnel at York College.

Because there were items from the project that included knowledge from both the solid mechanics and thermal-fluid sciences portions of the discipline, we split the deliverables of this project between the Machine Design course and the Thermal-Fluids laboratory course. The Machine Design course was concerned more with the structural design of the prototype, including selecting structural components to withstand the dynamic loads of a spinning wind turbine rotor. Additionally, students needed to provide analysis of the wind tunnel prototype as well as of the full-scale design.

The Fluid Mechanics laboratory deliverables focused on the aerodynamics of the system. Students used a freely available software package (Qblade) to analyze the aerodynamic performance of their proposed wind turbine designs. Students also 3D printed airfoil designs to be tested in the wind tunnel independently of the overall wind turbine. The validation of the data from Qblade regarding lift and drag forces became one of the laboratory deliverables.

This project also blended some instrumentation knowledge. To determine the power being generated by each wind turbine, the prototypes for the wind tunnel were required to be able to drive a small electric motor that was connected to a simple circuit of resistors. Voltage and current through the circuit were measured leading to a computed power level. Students were allowed to tune this circuit by selecting appropriate resistors that would maximize their prototype's power output. Thus, we incorporated electrical and instrumentation knowledge into the challenge.

Study Design

One of the primary questions we wanted to investigate was if, and how, this project changed our student's understanding of the integration of the sub-disciplines of mechanical engineering. For the purposes of this survey, we identified four key subdisciplines of mechanical engineering: solid mechanics, fluid mechanics, thermal sciences, and electronic integration and control. We surveyed our students before they began working on the project (mid-September 2022) and after the conclusion of the semester (February 2023). We asked the students to anonymously identify themselves with their mothers' initials so that we could track changes in individual's responses across the semester. The questions in this survey were broken into three distinct sections:

- Their relationship and understanding of mechanical engineering as a whole
- How they would describe their use and interest in solid mechanics, fluid mechanics, thermal sciences, and electronic integration and control.
- How they would describe their understanding of the integration of these subdisciplines.

The full survey can be found in Appendix B.

Results and Discussion

To begin, we wanted a baseline of how our students conceptualized mechanical engineering. We asked them, "describe what mechanical engineering is/what you think a mechanical engineer does in your own words." Their responses were coded thematically (**Fig. 1A**). While the highest percentage of students described the design, manufacture, and analysis/testing of machinery as the defining elements of mechanical engineering, many also highlighted the goal of engineering to solve problems to improve society in a safe and ethical way. While not explicit, their descriptions focus on machinery and do not clearly indicate the thermal-fluids or the electronic elements of mechanical engineering. This general idea that they will use solid mechanics knowledge more than fluid mechanics, thermal sciences, or electronic integration or control is also shown in what sub-discipline they expect to use most and least (**Fig. 1B**). Almost all our students (88%) anticipate using solid mechanics knowledge more than any other discipline in their future careers. It is worth noting, that while students anticipate using fluid mechanics (26%), thermal sciences (32%), and electronic integration and control (41%) least, these are at similar levels. This relatively even distribution of lower usage is likely informed by the types of jobs our students did on their Co-op the summer prior to this survey.

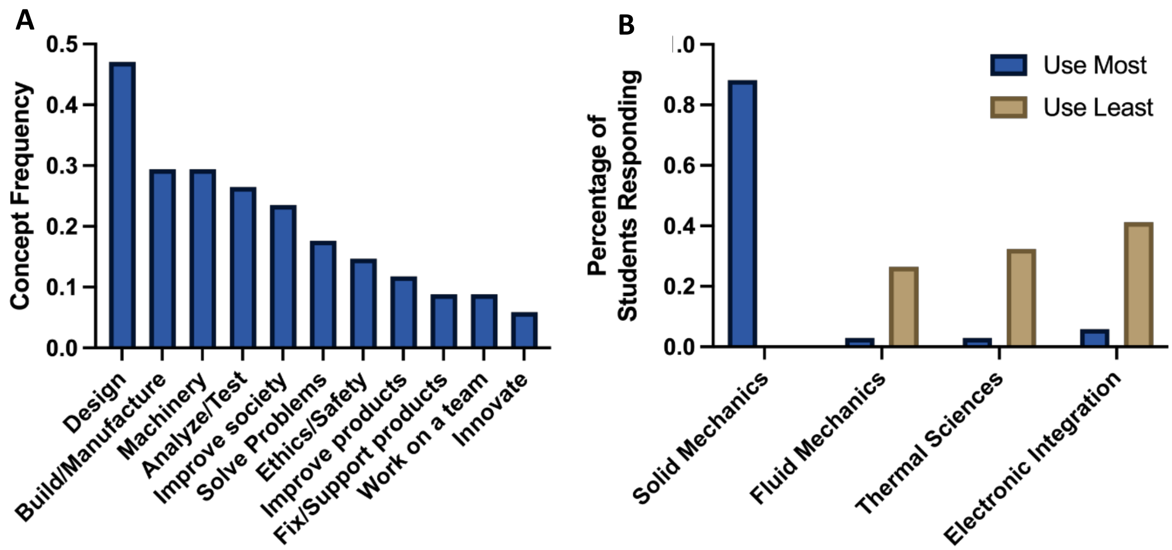

Fig 1. A) Thematic coding shows that students have a high-level understanding of mechanical engineering at the start of this project **B)** The majority of our student expect to use solid mechanics in their future careers more than other sub-disciplines.

Despite this clear weighting of the importance of solid mechanics in mechanical engineering, all our students felt that fluid mechanics was very well integrated with the rest of the engineering disciplines. More than half (53%) of our students gave examples subdiscipline integration in the context of thermal-fluid sciences (HVAC, powerplants, renewable energy, car exhaust/heat exchange). This is in stark contrast to students who described examples of integration from a primarily solid mechanics context (33%, machinery, military, car components) or electronic context (14%, automatic and sensors). This may be because the class had gone on a hydroelectric dam and power generation field trip the week before the survey was sent out. This experience of seeing fluids, coupled with the gear trains and turbines, may have influenced their responses.

When we compare pre- and post-data, we see that the wind turbine project stood out as a key example of integration to the students (**Fig. 2**). It is interesting to note that since the first survey was given after the project description was shared with the students, several of them (17%) already mentioned the project as an experience that helped them to learn about the integration of sub-disciplines even though they had not begun to work in earnest. After the completion of the project, 42% of students cited the wind turbine as an important example of how they were exposed to the integration of sub-disciplines, almost double any other example that was given. The second most prevalent example of an experience that helped students to see the larger integration of their coursework was Co-op. Continuing in the theme of non-solid mechanics courses informing their understanding of integration, Thermal-Fluids lab, Fluid Mechanics, and Mechatronics were the courses/labs that were cited as providing them exposure to integrating course content.

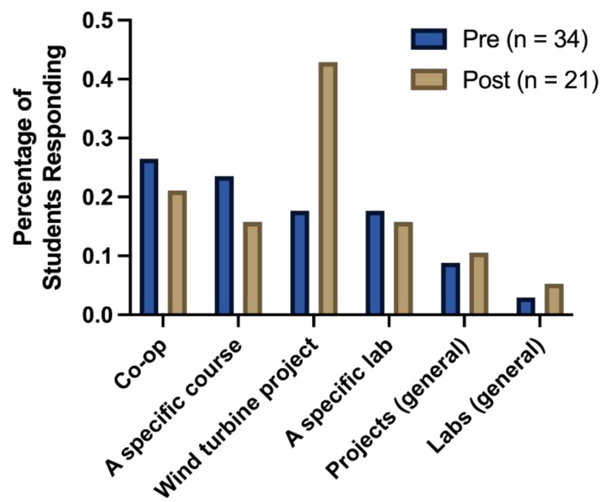

Fig 2. The wind turbine project was the highest ranked experience that informed the students understanding of the integration of multiple subdisciplines in ME.

Students had a wide range of responses when asked about how well they feel they have been exposed to problems where they had to integrate the sub-disciplines. While the average rating before and after the wind turbine project did not change (6.20 ± 1.99 and 6.053 ± 1.62, **Fig. 3A**), we saw an upward trend when we tracked individual student responses over time ($p = 0.0521$, **Fig. 3B**). On average, individual student ratings increased by one point with some students showing an increase of four points! Some of our student had already rated their understanding of integration very high (≥7/10). For some of those students, they indicated a decrease of one point after participating in the wind turbine project. This may be due to their realization that they did not know as much as they thought when they initially entered the project. As the sample size is small, continued investigation will be needed to verify a significant impact.

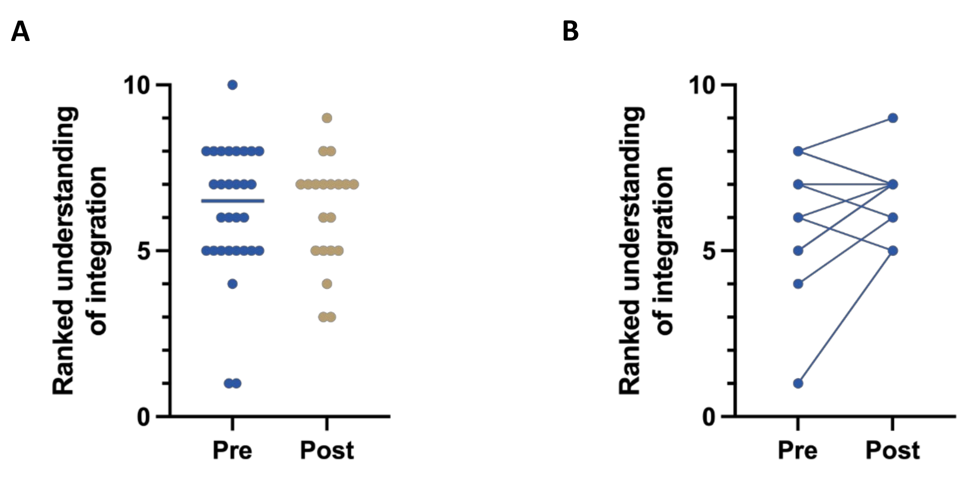

Fig 3. A) Average student rating of their understanding of curricular integration does not change due to the project. **B)** Individual student ranking shows an almost significant ($p = 0.0521$) increase in student rating after the project, n = 13 paired responses.

While student self-reporting of what they expected to use in their careers and what subdisciplines they most/least enjoyed remained unchanged due to the project, the examples of integration shifted to include more examples in a solid mechanics context. Students' responses included cars (again), but more students also mentioned machinery in general and the lubrication, heat generation, and other integrations of mechanical parts with thermal-fluid sciences. In addition, students were more likely to report that solid mechanics were least integrated (18% compared to 5%) and less likely to report that electronics were least integrated (22% compared to 47%) after the wind turbine project (**Fig. 4**). Students did perceive thermal sciences as least integrated, but it is interesting to note that it was the only sub-discipline that was not part of their curriculum during the F23 semester. Thermodynamics was a year prior and Heat Transfer is a year later.

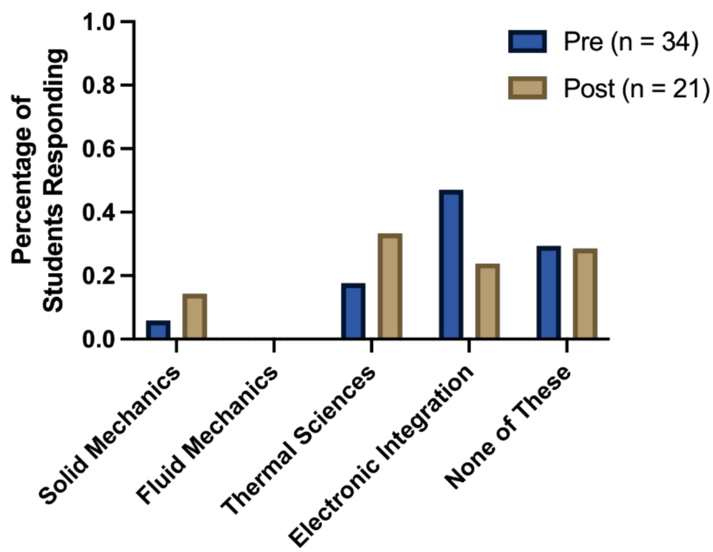

Fig 4. Students' appreciation for the integration of electronics in ME improved over the semester, while Thermal Sciences was ranked as less integrated at the end.

We will be holding a focus group over the summer to get additional insights into the students' thoughts on how the project impacted their understanding of mechanical engineering as an integrated discipline.

Conclusions

While it is hard to say how much their changing views are from the integrated wind turbine project specifically, it is apparent that the students' views regarding the integration of the parts of the Mechanical Engineering discipline did change across the semester. The high reporting of the wind turbine project as a means by which students learned and experienced this integration even two months after the semester ended support the notion that the project significantly contributed to this change. Further investigation though focus groups will help to clarify the impact of the project. For a more controlled comparison, we can investigate the impact of varying the project for the next offering. This may be done either by returning to a project mainly in the solid mechanics area (control) or by choosing a different integrated project such as a Stirling Engine or a water turbine.

Regardless of the path we take next year, we have decided to change some of requirements for an integrated project. An unintended consequence of students using the 3D printers to make the airfoils was that students then wanted to use the 3D printers to fabricate all components of the project. This resulted in students 3D printing square bases and cylindrical shafts instead of using the machine shop, which would have been both faster and more mechanically robust. It seemed that the 3D printer may have enabled the students to iteratively "engineer" without doing the prerequisite planning, designing, or calculating that would be necessary in subtractive manufacturing. It was clear that numerous students were printing, realizing they made a mistake, then re-printing. While 3D printing is useful for rapid prototyping, it does not replace robustness of mechanical design. Moving forward, we felt that this could be addressed by including some more direct information on the relative benefits and weakness of additive vs. subtractive manufacturing as well as mandating that certain components be machined instead of printed.

Anecdotally, many students told us that this project was cool and that they were excited to work on it. At our focus group over the summer, we will attempt to gain additional understanding of how the project impacted their appreciation for Mechanical Engineering, what elements of the projects the students felt were most or least helpful, if they feel it prepared them for their second Co-op, and if they have suggestions for improvement.

Overall, it seems that the project helped to provide a more nuanced view of Mechanical Engineering as an integrated discipline. While further development is needed to ensure the project provides the best possible learning outcomes for the students, students seem to have benefited from the integration of subdisciplines in the junior year curriculum.

References

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[2] V. Gajic, D. Heer, M. Macclary, G. Frost, and T. S. Fiez, “Holistic Mechanical Engineering Education with a Mechatronic Platform for Learning,” *IEEE Frontiers in Education Conference Proceedings,* Oct. 2004.

[3] M. A. Feldhausen, B.R. Babin, and E. Dringenberg, “Connected Mechanical Engineering Curriculum through a Fundamental Learning Integration Platform,” *American Society of Engineering Education Conference Proceedings*, June 2017.

[4] M.J. Traum, V.C. Prantil, W. C. Farrow, and H.L. Weiss, “Interconnecting the mechanical engineering curriculum through an integrated multicourse model rocketry project.” *American Society of Engineering Education Conference Proceedings*, June 2013.

[5] A. Smaili and S. Chehade, “Effective Integration of Mechatronics into the Mechanical Engineering Curriculum: A Cooperative, Project-Based Learning Model with Seamless Lab/Lecture Implementation,” *Int J Engng Ed.,* vol 21. no 4. pp. 739-744, Aug 2004.

[6] J. S. Rossman, C.L. Dym, L.B. Bassman, “Starting with the a-ha: An integrated introduction to solid and fluid mechanics,” *American Society of Engineering Education Conference Proceedings*, June 2015.

Appendix A: Suggested Course Sequence for Middle Semesters

Sophomore Year

Fall (18 credits)

MAT 272 Differential Equations 4 credit hours
EGR 250 Statics 3 credit hours
PHY 260 Engineering Physics: Electricity & Magnetism 5 credit hours
Disciplinary Perspectives or Foundations Course 3 credit hours
Disciplinary Perspectives or Foundations Course 3 credit hours

Spring (16 credits)

EGR 240 Mathematical Methods in Engineering 3 credit hours
EGR 290 Engineering Career Training Preparation 1 credit hour
EGR 264 Strength of Materials 4 credit hours
EGR 265 Materials and Solids Laboratory 0 credit hour
ME 270 Mechatronics 4 credit hours
ME 320 Thermodynamics 4 credit hours

Summer (2 credits)

ME 491 Engineering Cooperative Work Experience (Co-op I) 2 credit hours

Junior Year

Fall (18 credits)

EGR 342 System Modeling and Analysis 3 credit hours
ME 351 Instrumentation and Microprocessor Laboratory 1 credit hour
EGR 360 Fluid Mechanics 3 credit hours
ME 361 Thermo/Fluids Experiments 1 credit hour
ME 380 Machine Design 4 credit hours
Disciplinary Perspectives or Foundations Course 3 credit hours
Disciplinary Perspectives or Foundations Course 3 credit hours

Spring (2 credits)

ME 492 Engineering Cooperative Work Experience (Co-op II) 2 credit hours

Summer (14 credits)

ME 252 Dynamics and Vibration 4 credit hours
ME 260 Materials Science 3 credit hours
ME 261 Materials Science Laboratory 1 credit hour
ME 400 Capstone Design I 3 credit hours
ME 450 Finite Element Analysis 3 credit hours OR
EGR 392 Automatic Control 3 credit hours

Appendix B: Curricular Integration Survey

Q2 This survey is to help us collect data on how your views of mechanical engineering change as you progress through the curriculum. We ask that you express whatever you feel at the moment - there are no "right" answers. The survey will be completely anonymous, but we will use your mother's (or your most mother-like figure's) initials to help us track your answers over time.

Please enter your mother (or mother-like figure's) initials in the space below. For example. If you mother's name is Mary Elizabeth Smith, you would enter MES.

____

Q18 Are you a mechanical engineer?

- ○ Yes (1)
- ○ No (2)
- ○ Undecided (3)

End of Block: Explanation of the survey.

Start of Block: What is Mechanical Engineering

Q3 Why did you decide to major in mechanical engineering?

____

Q4 Describe what mechanical engineering is/what you think a mechanical engineer does in your own words.

____

Q5 What skills that you learn during your college education do you expect to be most useful when you leave and enter the workforce or a graduate program?

____

End of Block: What is Mechanical Engineering

Start of Block: Mechanical Engineering Sub-disciplines

Q6 Mechanical Engineering is often broken down into four broad sub-disciplines.
1. Solid Mechanics
2. Fluid Mechanics
3. Thermal Sciences
4. Electronic Integration and Control

Q7 Which of these broad sub-disciplines do you expect to ***use the most*** in your future?

○ Solid Mechanics (1)

○ Fluids Mechanics (2)

○ Thermal Sciences (3)

○ Electronic Integration and Control (4)

Q8 Which of these broad sub-disciplines do you expect to ***use the least*** in your future?

○ Solid Mechanics (1)

○ Fluids Mechanics (2)

○ Thermal Sciences (3)

○ Electronic Integration and Control (4)

Q10 Which of these broad sub-disciplines is ***the most exciting*** to you?

○ Solid Mechanics (1)

○ Fluids Mechanics (2)

○ Thermal Sciences (3)

○ Electronic Integration and Control (4)

Q9 Which of these broad sub-disciplines is ***the least exciting*** to you?

○ Solid Mechanics (1)

○ Fluids Mechanics (2)

○ Thermal Sciences (3)

○ Electronic Integration and Control (4)

Q11 Do you think there is a content/knowledge area that does not fall into one of these broad categories? If yes, please describe below. If not, answer no.

____

End of Block: Mechanical Engineering Sub-disciplines

Start of Block: Discipline Integration

Q12 What fraction of real-world engineering problems do you think require knowledge from multiple courses in different areas of the major (sub-disciplines) to reach a solution?

Give an example of how the sub-disiplines could be integrated if you can.

____

Q13 Which of these sub-disciplines do you think is least integrated into the overall concept of mechanical engineering as a whole (i.e. you are more likely to solve a problem without using that knowledge/content area).

○ Solid Mechanics (1)

○ Fluid Mechanics (2)

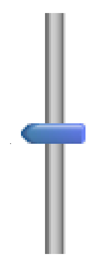
○ Thermal Sciences (3)

○ Electronic Integration and Control (4)

End of Block: Discipline Integration

Start of Block: Education

Q14 How well do you feel you've experienced the integration of these four sub-disciplines within your courses up to this point (10 would be excellent grasp of integration)?



0 (0)
1 (1)
2 (2)
3 (3)
4 (4)
5 (5)
6 (6)
7 (7)
8 (8)
9 (9)
10 (10)

Q15 What specific experiences have given you a feel for the integration of sub-disciplines in your education as a whole?

____

Q17 What is your current class year? (First year, sophomore, etc?)

If you are a non-traditional student, please answer with what class year the courses you are enrolled in are taken in a 4-year schedule. If you are in between a single class year, round to the one that you feel best describes your experience.

- ○ First year (1)
- ○ Sophomore (2)
- ○ Junior (3)
- ○ Senior (4)

End of Block: Education