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Instructing Creativity in Mechanical Engineering Design

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Independent Study

MEMS 400

Instructing Creativity in Mechanical Engineering Design

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Abstract

Employers depend on certifications to indicate whether or not a new hire has adequate skill levels for a job. From CodeAcademy courses to CAD tool classes, certifications reveal an applicants merit. In Mechanical Design Engineering coursework, representation of research, concept creation, design embodiment, and prototyping skills are often limited to a single project. In these courses, students are tasked with collaborating to produce a technically proficient and well-thought-out design. In order to advance the output quality of Mechanical Engineering Design coursework, I will provide criteria for course certification, and propose a system that can be used by professors to advance design learning, as well as increase the efficiency of design teams and project grading. First, analysis of existing design coursework will be performed. Challenges experienced in existing design curriculum will be compared against researched technical new product design processes and the insights of product designers in industry. Reflections on MEMS 411 design processes will serve as a baseline for embarking on the creation a Mechanical Design Certification tool, relevant to instructing creative design practices into strategic product development.

1 Introduction

In the Context of Massive Open Online Courses

A recent surge in technological development and improved access to manufacturing technologies has given rise to The Maker Movement. The maker movement is an "the umbrella term for independent inventors, designers, and tinkerers" [25]. The proposed course structure is designed to simulate the experience of an aspiring entrepreneur engaging in the maker movement through a design process in which Mechanical Design Engineering students develop the skills necessary to create novel, patent-possible designs and manufacturing plans.

Groups of makers and students alike can benefit from exercises that improve collaboration in design settings. To navigate an optimal route for prototype embodiment and future iteration, proposed comparative design exercises begin with well researched voids in the market place and a clearly identified problems. Collaborative brainstorming exercises and course requirements are proposed to aid students in identifying opportunities for disruptive innovation.

An emphasis on increased coordination of front-end design practices will enable teams to streamline concept development. As a more cohesive transition from MEMS 311, this structure will incorporate material learned in Machine Elements to service real design goals.

Research presented in the following report serves to explain alternative methods to creative design and iteration processes employed by industry experts. Applying this research to a semester-long course, proposed changes and course documents strive to guide creative design efforts into a well-articulated product design that can be useful to students interested in pursuing careers in both Research and Development, and New Product Design. Effective means for presenting a teams' path to design resolution will be useful to students hoping to prove their design skills to employers. With a focus on effective communication and group cohesiveness, the proposed structure will aid small groups in concentrating their efforts in and outside of the classroom - even if they are not in the same room.

In the Context of Massive Open Online Courses

Project team communciation of design details is difficult for both MEMS 411 students and credential seekers all over the world.

Massive Open Online courses, otherwise known as MOOCs have become extremely popular amoung people interested in picking up new skills. These individuals often do not have access to traditional routes of education. To help these people, quality professors at prestigious universities have worked to make online learning more accessible.

Stanford professor and Co-Founder of Coursera, Daphne Koller, explains in her TED talk that the greatest challenge to online courses is instructing creativity [?]. While many students all over the globe are provide the opportunity to learn subjects like math, science, and even writing, technological limitations of grading assignments make creative design projects unrealistic. Additionally, physical barriers prevent the hands-on experiences offered through traditional educational routes.

Another challenge of MOOC courses is real market value to employers, and more specifically, how students can gain college credit for their efforts. As indicated in a Wall Street Journal article, "new credentials don't carry much weight in hiring yet, recruiters say, because managers don't trust or recognize many of the companies and organizations behind the badges and courses" [26]. In a landscape that is "basically chaos," groups like the Luminia Foundation have identified a need for creating credentialing standards by building an online registry where employers and workers can search credentials [?]. The Credential Transparency Initiative is presently working on building a Credential Registry and Registry app which will allow users to access various credentials based on the following attributes shown in Figure ?? [27].

According to Stephen Crawford, a leader in the Credential Transparency Initiative at George Washington University, revealed that the CTI registry development will involve three main tasks:

1. Standardizing description terminology of credential features (students, workers, educators, employers)

2. Building a web-based platforms for organizations to post their information to the system

3. Building apps that facilitate customized searching and display of data on the registry

Much like a social networking cite, participating schools will be provided the opportunity to reveal to employers how skill credentialing is evaluated by their institution. Via email conversation, Stephen Crawford even indicated that " We'd love to have the Washington U. Engineering School post information about its Mechanical Engineering degree as part of the system for beta-tests that we are conducting. If a dean or academic leader is interested, please let us know" [?]. Although institutions providing access to traditional routes of education may not deem credential transparency as valuable to their institution, educator presence in the online community is one method in which institutions distinguish themselves as leader in a particular sphere of learning.

Circling back to the need for instructing creative learning processes, the changing landscapes of access to education and technology make effective design skills an asset to students all all over the globe.

With a primary focus on course improvement at my own Alma Mater, strategies for design collaboration and communication can be centralized such that students near and far can engage in exercises that further their abilities to effectively innovate and finalize mechanical designs.

2 Preface

In order to understand how to improve an existing Mechanical Engineering Design curriculum, I will first indicate the challenges incurred with each existing assignment. By first listing any and all challenges incurred by my team, indicated sections correspond to the "Solution" revealed later in this report. Key elements of each subsection are identifiable using the following legend:

- Existing Assignment
- Existing Example
- *Personal Insight*/ Comment
- **Proposed Solution Title:** Description
- Proposed Assignment

3 Review of Current MEMS 411 Experience

3.1 Task 0: Project Suggestion

Over the summer students are given the opportunity to provide project suggestions to MEMS 411 faculty. Each suggestion is assessed for viability and relevance to Mechanical Engineering coursework. Qualifying suggestions are made available for students to choose from, among other projects recommended by faculty or (a few) local businesses. Through this process, few students recommend projects, and many project recommendations were provided with vague or insufficient detail. The project list shown in Figure 1 below indicates Student suggested projects in parentheses.

MECHANICAL ENGINEERING – 411

PROJECT IDEAS LIST

1. Tabletop Dynamometer: A small dynamometer is needed for generating torque/speed curves of small motors and other rotating equipment.

2. Plate Pouring: biologists culture microbes on agar in Petri dishes under aseptic (sterile) conditions. A biologist can pour their own plates or purchase them for $4 each on Amazon. To save time and reduce costs, a biologist at the STLCC Biobench CRO wants to pour plates in the lab with the aid of an automated process.

> To automate the pouring process, a design is needed that contains a reservoir for agar medium, a valve to regulate flow of the medium, and a mechanical device to time motion and move plates for the pour. The biologist wants to control the pouring system with a laptop. The system must fit into a hood, be sterile, easy to clean, and allow the biologist to pour 120 plates per hour. (External Customer)

3. Machine that can be programmed to fold various designs of **Paper Airplanes (electronics allowed)**

4. Centrifugal Governor / Flywheel / Clutch. Design a clutch/flywheel system for a rotating shaft roughly the size of what you built in the 311 lab. A motor-driven shaft would bring a flywheel up to speed via a clutched connection.

5. Machine that will **Un-Crumple Paper**: An academic exercise on material manipulation. Input = a crumpled ball of photocopier paper and output = a flattened sheet.

6. Watermelon Washer \ Server: This is for bigger watermelons, which are difficult to handle when washing the rind prior to cutting. Design a system that facilitates (1) washing the rind before cutting; (2) Cutting the first disk from the melon; (3) Catching the two "halves" after cutting the first disk; (4) Sealing the exposed surface of the two halves as is now commonly done with plastic wrap; and (5) storing the "started" watermelon in the refrigerator.

7. Saran Wrap Handling Device: Device to improve the process of wrapping a made sandwich with plastic cling wrap.

8. Convertible multi-shape backpack: Fundamentally a backpack, but transforms among a number of shapes and sizes. (student suggested project)

9. Multi-axis vibration isolation mechanism for filming video: (student suggested project)

10. Ultralight collapsible street legal moped concept: (student suggested project)

11. 2016 ASME Design Competition: This year's challenge is to build a compact engineering system in order to manufacture a projectile from a standard sheet of paper and test it by propelling it a maximum distance. The testing will take place on a competition course that consists of a 3 meter wide strip along the length of the room, with a 1.5-m x 3-m setup area for your system at one end. (ASME will fund your project, and possibly a trip to the regional competition in the spring)

12. Plant growth experiment maintenance and control system:

An automated system to weigh potted plants in a greenhouse/growth chambers at consistent intervals (5 – 30 minutes) and apply a precise amount of water once per day. This enables us to accurately administer different environmental treatment regimens and log data that will help us study water usage and plant growth on a genetic level. (External customer)

13. Athletic Mouth Guard Project 1: will determine the load path and load transfer with load and stress analysis of transverse pins in the ethylene vinyl acetate (EVA) matrix. It is proposed that analysis be performed initially by hand, and then with ESRD's Stress Check (ESRD.com) which is currently available to MEMS 411 students. In particular, analysis will include the dimensioned vertical thickness of the mouth piece corresponding to the user's individual physiological position, transverse pin dimensions, and the ability of transverse pins to partition occlusal forces. The following questions may be relevant.

Golden Bite™ mouth guard is a patented, pre-formed, mass producible, low cost boil and bite mouth guard manufactured with DuPont's ethylene vinyl acetate (EVA). Golden Bite™ mouth guard enhances athletic or work performance on par with improvement provided by more expensive made-to-measure mouth guards. (External customer)

> Is partitioning complete or are significant remaining occlusal forces present during mouth guard use?
>
> Does transfer pin moment or torque effect partitioning of occlusal forces?
>
> Is transfer pin length sufficient to provide full partitioning?
>
> Will a transfer pin with lingual fixed ends improve partitioning? That is, if left and right transfer pins were connected to each other as a single pin spanning from the left to right buccal pin ends, will the transfer pin be stabilized through elimination of bending moments and torques present on the lingual end of the two transfer pins in the current mouth guard?

14. Athletic Mouth Guard Project 2: will study the effect of Golden Bite™ mouth guard on performance of a student athlete. For this project, it is given that adequate partition of occlusal forces relieves muscle structures and alleviates pain through the use of embedded transverse pins within the base wall of the mouth guards, on the left and right posterior portions. Biomechanical analysis of the mandible, musculoskeletal load path, or load transfer will evaluate the ability of Golden Bite™ mouth guard to fully or partially relieve forces on muscle structures. (External Customer)

> Typical loads are due to athletic and work-related overextension injuries that result in sprained and torn muscles, tendons, and ligaments, back injuries, and herniated disks. This project will seek to demonstrate benefits of mouth guard use directly through measurement of forces. Alternatively, mouth guard benefits will be measured indirectly through student athlete performance enhancement while wearing Golden Bite™ mouth guard.

15. Ice Resurfacer: Commonly, ice skating rinks are made smooth with a Zamboni, a large gas powered device that removes a thin layer of ice, and lay down a smooth layer of water to create a fresh skating surface. Redesign this process to be human powered. (Student suggested project)

16. Drone: Design and build a flying drone that can capture images or video of the WashU campus. Safety first! (Student suggested project)

17. Wingsuit: Design an optimized wingsuit design to improve lift performance. (Student suggested project)

18. Whiteboard pen dispenser: Have you seen your favorite teachers show up to class with their own whiteboard markers? Tired of struggling to see writing on the whiteboard because the pens kept in the room are out of ink? Design a whiteboard pen dispenser for classrooms so that students and professors can use their WUSTL ID to borrow a pen. (Student suggested project)

19. **Gas turbine prototype:** Design an experimental gas turbine test rig that allows the insertion of different combustion chamber shapes. Note that fuel may not be burned during the class. (Student suggested project)

Figure 1: ***MEMS 411 Fall 2015*** **Project Ideas List** [?, ?]

3.2 Task 1: Elevator Pitch Assignment

3.2.1 Existing Method

On the provided list of approved projects (Figure 1), project descriptions vary from one line to an entire paragraph. Selecting a topic from this document, each student is tasked with presenting a 30-second verbal elevator pitch for the class, accompanied by a one-slide 30-second YouTube presentation.

Assignment requirements include:

- Brief description of solution
- Background information, including a short list of relevant patent numbers
- Sketch of concept
- Alternative project preferences

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MECHANICAL ENGINEERING DESIGN PROJECT

Background information study – (11% - individual grade, includes 2% for group consultation with Librarian Lauren Todd). The 2% earned when your group meets with Lauren Todd is added to your grade after your meeting with her. You'll earn 6% of the 8% grade for this assignment when you complete the elevator pitch.

Description: Identify your favorite design project among those that were presented in class. For this project, you must find information and produce the following:

1. A short design brief. What is the design problem?
2. A summary of the most relevant background information, such as similar existing devices or patents. Provide patent numbers, URL's, etc.
3. A basic concept sketch for a possible solution.
4. Identify (by their unique names) two other projects, numbering them as 2 and 3, which you would be willing to work on for the term.

To get some of the needed information, you may have to meet with one of the instructors, or the client that provided the project.

Upload 1-4 to YouTube as a presentation. Your YouTube presentation should not have audio. The four parts should be numbered and labeled with the following headings in bold capitals: **BRIEF, MOST RELEVANT, CONCEPT SKETCH, CHOICES 2-3.** This file will be used as your "overhead" during a one-minute elevator pitch that you will give to the entire class.

Slide must be submitted by 5 pm on Sunday August 30th. Absolutely no exceptions. No thumb drives will be allowed the day of the presentation.

Clarifications and advice:

1. Listen carefully to the elevator pitches of others to decide which project and which team interests you.

Grading: You will be graded on the quality/presence of each of the following in your elevator pitch.

1%	Design brief
2%	Background info
2%	Concept sketch
1%	Choices 2-3
2%	Library group consultation (after teams are formed)

Instructions for uploading your PowerPoint presentation to YouTube.

Allow others to easily view and share your newly created slide show video by publishing it to the Web. It's a great way to distribute information and keep track of who is viewing your presentation. Publishing your slide show video to YouTube is one of the easiest ways to host it online free of charge and take advantage of the benefits listed above.

1. In PowerPoint 2010, create a video (.wmv file) from your slide show.
2. Download and install Windows Live Movie Maker.
3. In Windows Live Movie Maker, on the **Home** tab, in the **Add** group, click **Add videos and photos**.
4. In the **Add Videos and Photos** dialog box, open the folder that contains the photos or videos that you want to add, click the photos and video files, and then click **Open**.

   Note: To select multiple photos and videos, press and hold the Ctrl key, and then click each photo and video you want.
5. To publish your movie to YouTube, in Windows Live Movie Maker on the **Home** tab, in the **Sharing** group, click **Publish on YouTube**.
6. In YouTube, enter your YouTube account name and password, and then click **Sign In**.

   Tip: If you have not done so already, Create a YouTube account.
7. Enter a title, description, and any tags that you want to add to your movie.
8. Select a category, choose whether you want your movie to be public or private, and then click **Publish**.
9. In the **Your movie has been published** message, click **View online** to watch your movie on YouTube.
10. The least blurry way to upload a slide on a Mac is the following:

    1. Save PowerPoint as an image
    2. Upload image to "my photos" on Google+
    3. Go to YouTube and click "upload"
    4. On the right hand side click "photo slideshow"
    5. Upload photo from Google+
    6. Upload the same photo 6 times in total
    7. Set "slide duration" to 10s (thats the max)
    8. Set "Slide effect" to none
    9. Set "Transition" to crossfade (since it is the same image nothing happens)
    10. Indicate "no audio"
    11. Then click upload (change the name and description here)
    12. Click "publish"

Figure 2: ***MEMS 411 Fall 2015*** **Background Information Study** [?, ?]

3.2.2 Existing Resources

Students are provided two examples for how to format their presentation slide. Although instructions indicate that the Elevator Pitch slide must include a sketch, only one of the provided examples successfully provides a sketch (which in actuality is a light and unclear drawing). A few descriptive words provide students a fundamental understanding of what their peer is attempting to achieve.

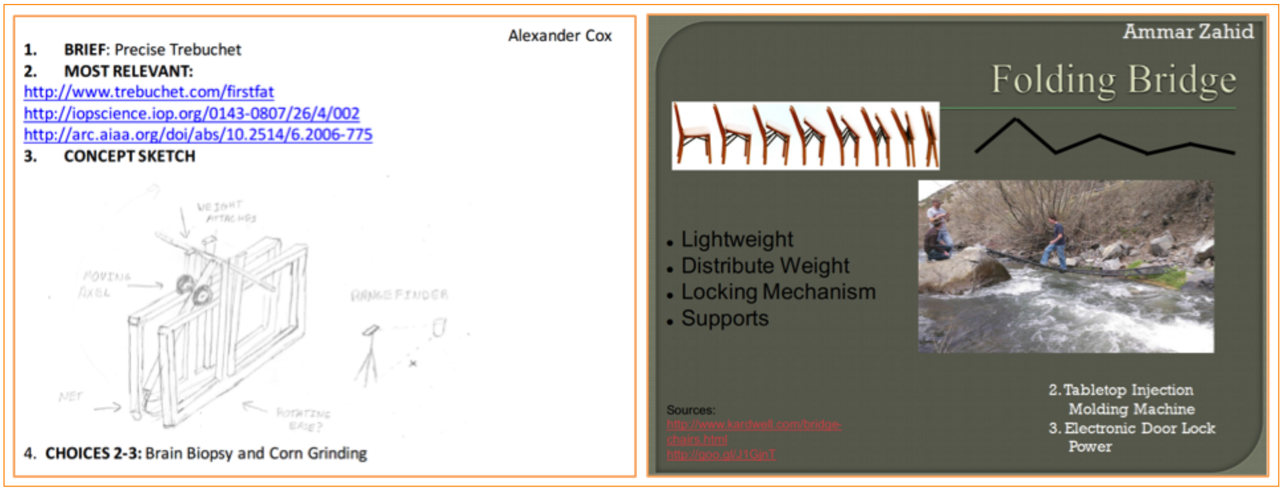


Figure 3: *MEMS 411 Fall 2015* Elevator Pitch Slide Examples [?, ?]

Student submissions are compiled in to a comprehensive video stream, such that (nearly) all elevator pitches can completed in one class period. As a swift presentation arrangement, students to have no opportunity to run overtime. This coordination comes at the expense of accessible slide information. Research citations are posted on each slide, however, these links are not not accessible (since slides are compiled into a YouTube file). The goal of this exercise is for students to gain exposure to classmates with similar topic interests.

Following the elevator pitch presentations, students can review the project submissions via YouTube. Reassessing classmate project interests is challenging, since presentation slides are organized by submission time rather than project topic. Also distracting, each slide represents vital information differently. Shown below in Figure 5 is an assortment of elevator pitch slides from Fall 2015. A close look at 2 reveals a bicycle driven pump on the first slide, and 14 slides later, another submission of this same project. These slides were presented to MEMS 411 students in the Fall of 2015 as examples. Visibly, the existing format is cluttered with inefficiencies, making it difficult for students to navigate team formation based on mutual passion for a design topic.

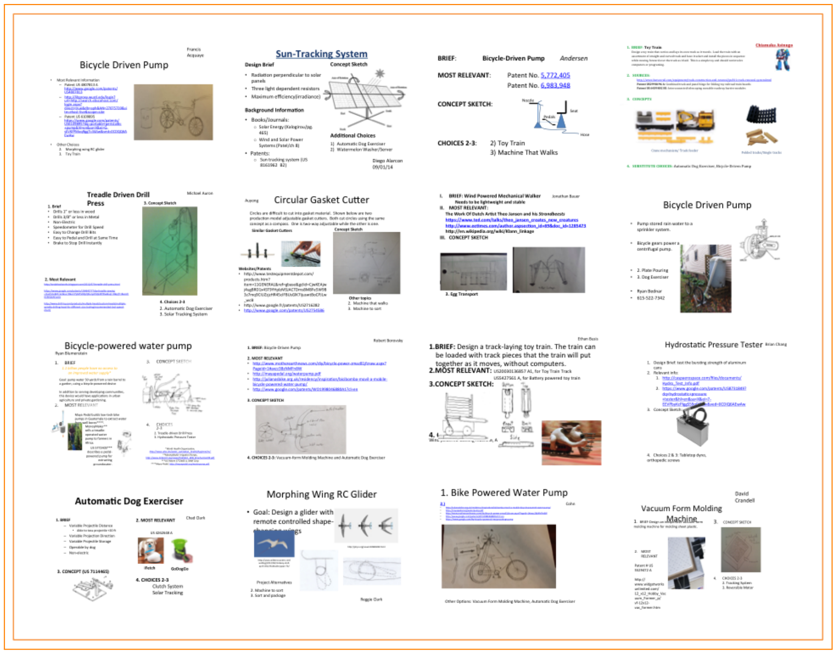


Figure 4: ***MEMS 411 Fall 2014*** **Student-Submitted Elevator Pitch Slide Examples** [?, ?]

Students could additionally benefit from improved access to classmate contact information (WUSTL email address), and a course "reception" where classmates can assemble and connect over design topics presented that day.

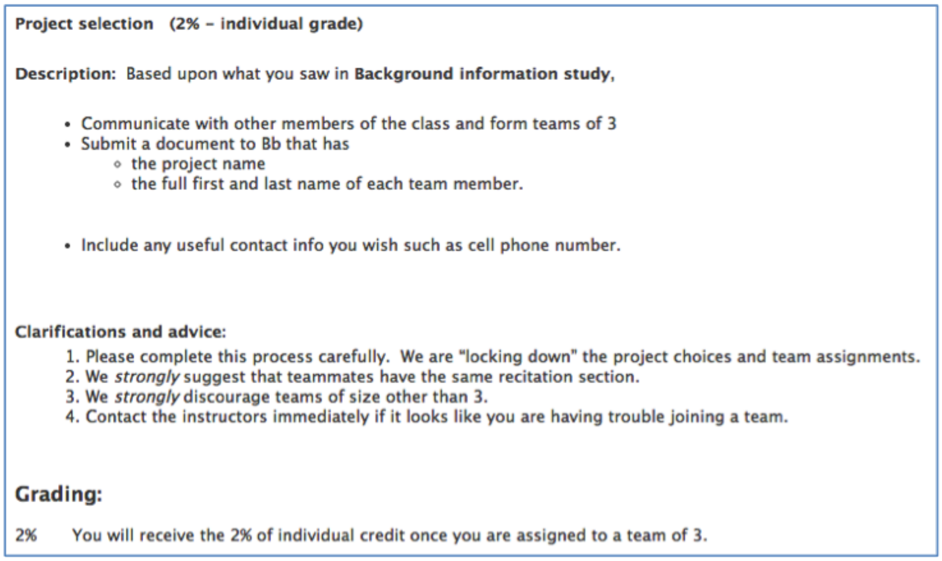
Solutions: MEMS 311:Project Suggestion Assignment Project Presentations

3.3 Task 2: Project Selection Assignment

3.3.1 Team Formation

In a landscape dominated by friendships, project group formation reveals that many students are risk adverse. Teams that were not formed from to prior friendship often run the risk of containing stratified levels of accountability and skill. Often, these shortcomings result in dysfunctional teams that struggle to produce a quality design project. On the other hand, students who stick with their friends experience limited access to projects they are genuinely drawn to, as they forfeit a concept of interest for conformity.

Concept-based team selection should be encouraged and better facilitated by MEMS 411 faculty. As shown below in Figure **??**, students are given no aid in the project selection process.



Project selection (2% – individual grade)

Description: Based upon what you saw in **Background information study**,

- Communicate with other members of the class and form teams of 3
- Submit a document to Bb that has
  - the project name
  - the full first and last name of each team member.

- Include any useful contact info you wish such as cell phone number.

Clarifications and advice:

1. Please complete this process carefully. We are "locking down" the project choices and team assignments.
2. We *strongly* suggest that teammates have the same recitation section.
3. We *strongly* discourage teams of size other than 3.
4. Contact the instructors immediately if it looks like you are having trouble joining a team.

Grading:

2% You will receive the 2% of individual credit once you are assigned to a team of 3.

Figure 5: *MEMS 411 Fall 2014* Project Selection Assignment [?, ?]

3.3.2 Work Planning

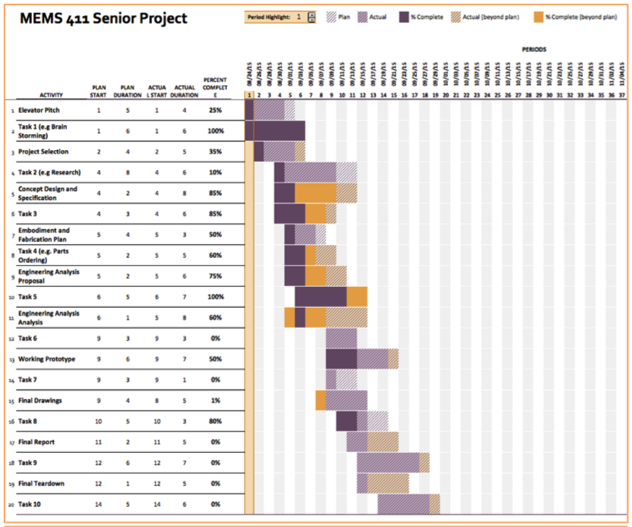
What most students do not realize at the start of the semester is that depending on which role a teammate assumes, ones' project workload dramatically changes over the course of the semester. At the start of MEMS 411 in Fall of 2015, no clear syllabus of assignment due dates was provided to the class. Without a clear understanding of how important any given assignment was to a students' grade, in relation to future tasks, students worked through assignments "paycheck-to-paycheck."

Finally, late into the semester, a Gantt Chart, shown below in Figure6, was provided for students to assess assignment completion task-by task. By the time teams were given access to this document, most had already experienced irreconcilable time management conflicts that prevented them from entering the machine shop with neither a clear work plan, or thorough design specifications.

Without either a structured (or strictly required) method for work hour documentation, or an estimated minimum time to task completion, it was difficult, even with the Gantt chart, to gauge whether teammate contributions were fully servicing the needs of the necessary step of development.

3.4 Task 3: Conceptual Design and Specification

Successful concept development hinges on a conclusive understanding of ones consumer, and what problems their consumer faces. A conclusive understanding of what specific problem a team



	ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
1	Elevator Pitch	1	5	1	4	25%
2	Task 1 (e.g Brain Storming)	1	6	1	6	100%
3	Project Selection	2	4	2	5	35%
4	Task 2 (e.g Research)	4	8	4	6	10%
5	Concept Design and Specification	4	2	4	8	85%
6	Task 3	4	3	4	6	85%
7	Embodiment and Fabrication Plan	5	4	5	3	50%
8	Task 4 (e.g. Parts Ordering)	5	2	5	5	60%
9	Engineering Analysis Proposal	5	2	5	6	75%
10	Task 5	6	5	6	7	100%
11	Engineering Analysis Analysis	6	1	5	8	60%
12	Task 6	9	3	9	3	0%
13	Working Prototype	9	6	9	7	50%
14	Task 7	9	3	9	1	0%
15	Final Drawings	9	4	8	5	1%
16	Task 8	10	5	10	3	80%
17	Final Report	11	2	11	5	0%
18	Task 9	12	6	12	7	0%
19	Final Teardown	12	1	12	5	0%
20	Task 10	14	5	14	6	0%

Figure 6: *MEMS 411 Fall 2014* Gantt Chart Overview [?, ?]

wants to solve, how this problem is currently solved, and how present technology is missing the mark must be prepared by teams. Successful research and utilization of research during the design process enables teams to tap into the mentality of their target market consumer. Therefore, successful concept selection weighs heavily on how critically a team chooses to address a design problem.

3.4.1 Needs, Metrics, and Quantified Needs

Given merely two weeks to administer customer interviews, narrow customer complaints into a metric list, and generate a table of needs; concept design stages are forced upon students before they are ready.

Without adequate time to fully understand the root of their problem and verify their consumers feedback with thorough interview processes, students begin sketching ideas that incorporate any and all metrics that their consumer identified to resonate with.

Although students approach this course and team formation with an identified problem, immediately following their first user needs interview, any preconceived idea of a problem is often clouded by the desire to service every need of their target consumer.

Over complication of a design by incorporating too many conflicting design elements ultimately will not end well for a design team since teams have very limited time for prototype iteration. Implementation of an array of functions often detracts from a design's ability to perform any one function successfully. A good example of this is my own Senior Design project:

Contextual Example:

My team designed a wheeled structure that could be used as a child carrier backpack, stroller, or as a changing surface. What we created was a backpack that lacked parent-child comfort, stability, and ease of use. Although a low priority, the child-changing surface we'd hoped to have above ground, wound up in an extremely unsafe place - on the ground next to the wheels. The stroller functionality resulted in a luggage-like roll-behind design. This would likely uncomfortable for the child, without large wheels or means to mediate vibrations. We'd also hope for our child carrier to fit in an overhead luggage compartment. Consequently, transitional design goals were stifled in our overly small envelope. With a shoe-string budget that prevented our team from adapting existing child carrier or stroller designs, successful execution of all design goals we set for ourselves became impossible. Meanwhile, a substantial amount of time and effort was dedicated to ensuring that our prototype *functioned as a freestanding structure. Although ability to stand upright was a defined metric, it was not a pinnacle goal for our team, nor a functional selling point to our consumer.*

Ultimately, our team didn't not say no to a single design suggestion. Overwhelmed by geometric complexity, keeping all teammates on the same page was a source of frustration and anxiety. Meanwhile, our team unanimously forgot our mission: which was to improve on existing child carrier backpacks.

In part, this issue can be attributed to selecting the wrong target customer. It so happened, that the individuals grading our projects also provided us with our customer interview. Eager to deliver a product that our professors could get exited about (by exceeding their expectations with every function they suggested), we failed to zero in on one function that had legitimate novelty.

A team therefore must have a basis for mutual understanding of the teams' problem prior to brainstorming concept ideas, or administering the consumer interview process. The ability to relate any suggested design element to a concrete mission will help teams assess what items are most relevant, and move on to discerning how to leverage resources to fully service desired functions in a strategic way.

3.4.2 Concept Drawings

Traditionally, concept development and sketching was integrated with Machine Elements (MEMS 311) learning. Tasked with sketching solutions to design problems, students were assigned exercises that challenged them to think creatively. First, ideas were expressed as 3-dimensional chicken scratch sketches, with consecutive sketches of increased design refinement. Over time, essential research findings and metric considerations necessary for design accuracy were incorporated into a finalized design embodiment.

Effective spring of 2016, MEMS 311 curriculum eliminated student exposure to practicing visual communication of design concepts. With a shift in focus to more thorough machine elements learning, the landscape of concept development abilities entering MEMS 411 revealed the dramatic change. Beginning fall of 2016, students will need to learn the practical skills of concept development and drawing through the context of senior design coursework.

Despite curricular changes and any attempts to teach students to sketch, inevitably, some teams will grapple with different visual communication styles and abilities. Unless extremely articulate, students who lack the ability to sketch are often of little help in concept generation. Each group member must have at least one element that helps them to feel invested in the project. This will help teammates feel ownership over a particular element or contribution they made, which keeps them invested in the project.

Solution

Students need a better way to score concept designs and prioritize metric requirements such that no idea is immediately ruled out, but focus is maintained.

3.5 Embodiment

Where originally rushed into the embodiment phase, teams that do not choose to produce a CAD or SolidWorks design file for this project submission experience significant challenges in communicating design specifications to teammates during the construction phase. Therefore, digitally produced renderings should be a requirement. In addition to this, the comprehensive list of parts should be included in the presentation of digitally produced design drawings.

Manufacturing processes plans were not required for this assignment, and ultimately should have been. Had this been the case, teams could have more effectively distributed labor, as the significance of design roles shifts over to construction and part ordering responsibilities.

4 Review of Existing MEMS 411 Structure

The weight of each graded assignment is translated into a measure of time based on anticipated weekly workload for a 3-credit course. Workload distribution over the course of the semester reveals that team success is dramatically influenced by how well design documents are prepared before 9/30/15. At this date, the design embodiment is due. This assignment serves to guide the development of a design by setting forth a plan of action for manufacturing and ordering parts necessary to create a functional prototype.

Actual Distribution of Workload For teams who are unable to develop a precise concept by this (early) date, the embodiment assignment cost the team time and energy. This leaves teams confused and lacking the time they needed to create an embodiment design that fully captures their desired concept design.

The table below shows sub-sections of major project assignments, and how much time must be given to each assignment, provided that a team performs based on an "actual timeline," experienced by a team prone to procrastination.

Projected Time commitment =			9	class hrs/wk	126	class hours/semester
			6	hw hrs/wk	84	hw hours/semester
	1	Credit =	3	class hours/week		
	1	Credit =	2	hw hours/week		
	1	semester =	14	weeks		
	1	MEMS 411 =	3	credits		

MEMS 411: Mechanical Engineering Design Project				Dr. Malast, Dr. Jakeila			Total Time Commitment		
"Actual" Project Scenario where student begins preparing final documents on 11/16/15									
Due Date	Window for completion (between submissions)	Days into semester	% of grade	Description, Sub-Topics	Class Hours	HW Hours	Section	Subtopic	Rate of task completion (hours/day
8/24/16	0	100	3%	**Work Logbook (Individual)**	3.78	2.52	6.3	6.3	0.063
	100	100	2%	**Attendance (Individual)**	2.52	1.68	4.2	4.2	0.042
8/30/15	6	6	11%	**Background, Codes, Standards (semi-individual)**	13.86	9.24	23.1	23.1	3.85
		4		1% Design Breif				2.1	3.85
				2% Background Info				4.2	
				2% Concept Sketch				4.2	
				1% Choices 2-3				2.1	
				2% Library Group consultation				4.2	
		0		3% ???				6.3	1.05
		4	2%	**Project Selection**	2.52	1.68	4.2	4.2	1.05
9/16/15	17	23	15%	**Conceptual Design & Specs. Study**	18.9	12.6	31.5	31.5	1.85294118
		6		4% *Needs, Metrics, Quantified Needs*					1.85294118
				2% Interview				4.2	
				1% Metric List				2.1	
				1% Needs Table				2.1	
				5% *Concept Drawings*					
				3% Drawing Quality				6.3	
				1% Designs Different				2.1	
				1% Desings good (w/ constraints)				2.1	
				4% *Concept Selection*					
				2% Scoring				4.2	
				1% Preliminary Physcial Analysis				2.1	
				1% Summary Statement				2.1	
		23		2%% Performance Goals				4.2	2.25
9/30/15	14	37	15%	**Embodiment & Fabrication Plan**	18.9	12.6	31.5	31.5	2.25
				Drawing Quality					
				5% (embodiment/assemply drawing)				10.5	
				2% Complete info on parts list				4.2	
				4% Quality of individual part drawings				8.4	
				Correctness and completeness of design rationale/ engineering					
		37		4% analysis				8.4	0.6
10/5/15	7	44	2%	**Engineering Analysis Proposal**	2.52	1.68	4.2	4.2	0.6
11/30/15	0	44	10%	**Engineering Analysis Results**	12.6	8.4	21	21	0.25
11/16/15	42	86	5%	Initial Prototype Demo	6.3	4.2	10.5	10.5	0.25
11/30/15	0		15%	**Working Prototype**	18.9	12.6	31.5	31.5	
				7% Final Prototype Demo				14.7	
				Documentation in final report					
				8% template				16.8	
				4% One working video				8.4	
				4% Photos and documentation				8.4	
11/30/15	0		5%	**Final Drawings**	6.3	4.2	10.5	10.5	
11/30/15	0	86	5%	**Final Report**	6.3	4.2	10.5	10.5	6
11/30/15	14	100	5%	**Final Presentation**	6.3	4.2	10.5	10.5	6
		100							2.1
12/5/15	5	105	5%	**Final Tear Down**	6.3	4.2	10.5	10.5	2.1
							210	hours	

Figure 7: *MEMS 411 Fall 2016* Actual Workload Distribution [?]

Students are prone to procrastination will seize the opportunity to coast whenever possible. The Actual plot of a procrastination-prone team is shown below. A conspicuously stacked front end of course assignments allows students to flounder in the middle of the term, as they put tasks off to last minute.

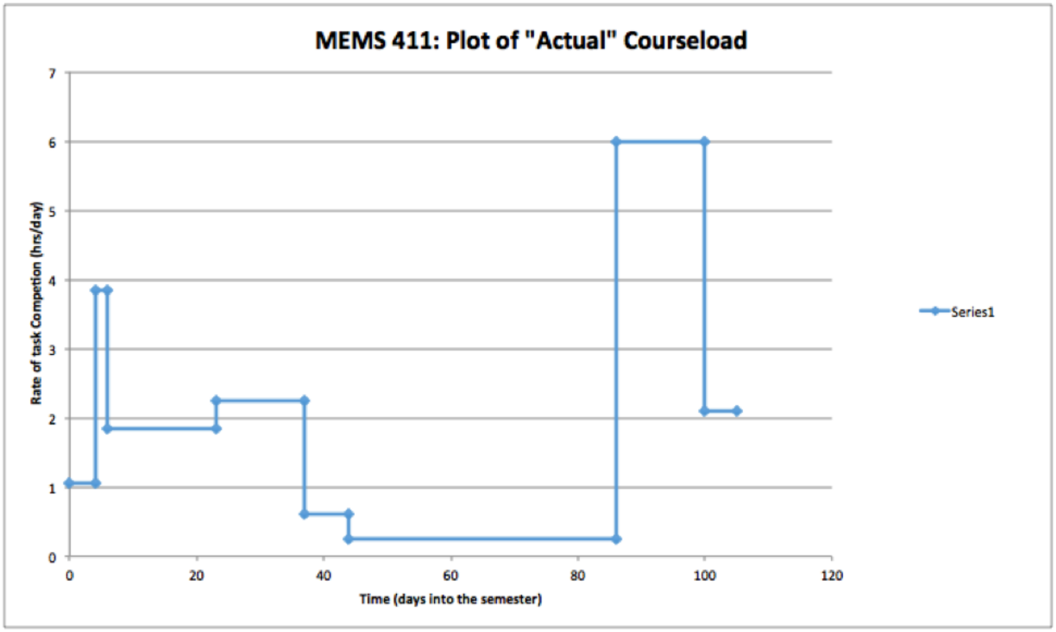


Figure 8: ***MEMS 411 Fall 2016*** **Actual Workload Distribution** [?]

This distribution of labor hours is unfair to teams. Students are not given ample time to produce embodiment drawings that successfully drive prototype construction. An artificial urgency to finalize all design specifications within the first month of class leaves additional time where students must "clean up the mess they made" in their first attempt at designing a desired function. Although the early due date is intended to prepare students with embodiment drawings before the onset of midterms, the result is rushed preparation of mediocre drawings (often hand-drawn) that will be of no actual service to a team while assembling a prototype.

This structure is conducive to producing a prototype, but not necessarily a prototype that successfully achieves its desired function. If students are extremely organized, on task, and come out of the gate running, they will exhibit results similar to the Ideal case, plot below.

Ideal Distribution of Workload Achievement of the ideal distribution, shown below in Figure **??**, is dependent on the team having all-hands-on deck. This remains relevant throughout the course of the semester. For instance, if a student takes a step back from building the prototype, their teammates will delegate the responsibility of the final report to this team-member. However, if this member was absent for construction, he or she is unaware of why design decisions were made, and how they were justified.

In an ideal world, every member is capable of contributing to the design-build, or at minimum can contribute to the CAD drawings or manufacturing plans necessary to producing a physical prototype. Any person who cannot contribute in either of these ways can be delegated research tasks, but these hold little relevance except at the very beginning and very end of the semester. Regardless of these benefits, if tasked with working on the final report, if said absentee group member did not engage in construction, they will not be able to explain justifications and insights regarding elements of the teams' finished prototype.

MEMS 411: Mechanical Engineering Design Project				Dr. Malast, Dr. Jakeila			Total Time	
"Ideal" Project Scenario where student begins preparing final documents on 9/30/15							Commitment	
Due Date	Window for completion (between submissions)	Days into semester	% of grade	Description,	Class Hours	HW Hours	Section	Rate of task completion (hours/day
8/24/16	100	100	3%	Work Logbook (Individual)	3.78	2.52	6.3	0.063
	100	0	2%	Attendance (Individual)	2.52	1.68	4.2	#DIV/0!
8/30/15	6	6	11%	Background, Codes, Standards (semi-in	13.86	9.24	23.1	3.85
	4	4	2%	Project Selection	2.52	1.68	4.2	1.05
9/16/15	17	23	15%	Conceptual Design & Specs. Study	18.9	12.6	31.5	1.85294118
9/30/15	14	37	**15%**	**Embodiment & Fabrication Plan**	18.9	12.6	31.5	2.25
10/5/15	7	44	2%	Engineering Analysis Proposal	2.52	1.68	4.2	0.6
11/30/15	60	44	10%	Engineering Analysis Results	12.6	8.4	21	0.35
11/16/15	42	86	5%	Initial Prototype Demo	6.3	4.2	10.5	0.25
11/30/15	60	100	15%	Working Prototype	18.9	12.6	31.5	0.525
11/30/15	60	100	5%	Final Drawings	6.3	4.2	10.5	0.175
11/30/15	60	86	5%	Final Report	6.3	4.2	10.5	0.175
11/30/15	60	100	5%	Final Presentation	6.3	4.2	10.5	0.175
12/5/15	5	105	5%	Final Tear Down	6.3	4.2	10.5	2.1
							210 hours	

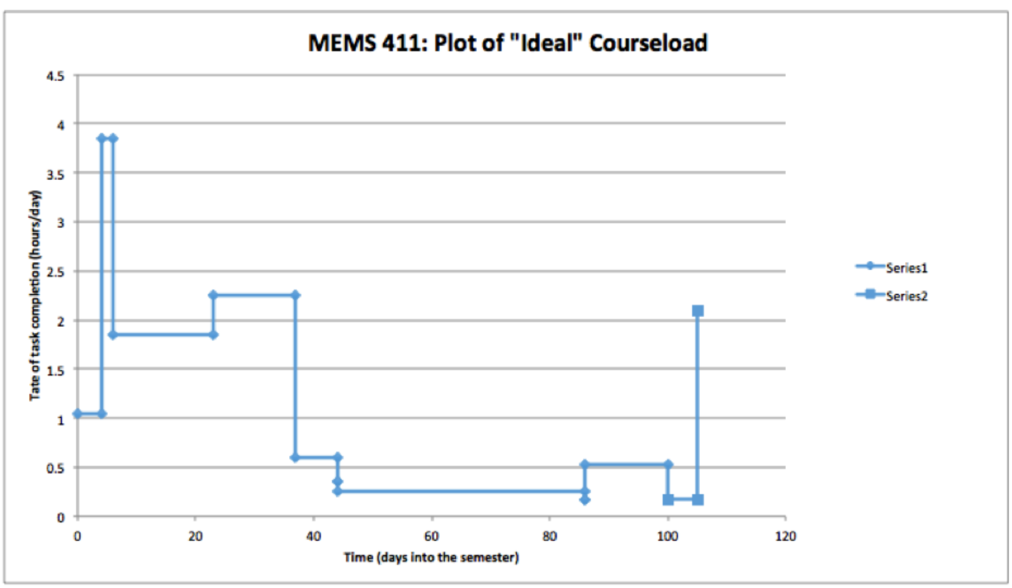


Figure 9: ***MEMS 411 Fall 2016*** **Ideal Workload Distribution** [?]

Workload distribution indicates a tremendous imbalance between front, end, and middle of the course workload requirements. As described by Dr. Malast, the push for students to complete concept and embodiment assignments early in the semester is to allow adequate time to finalized designs before other classes and midterms dominate students schedules. Logically, a workload distribution like this does students a favor by forcing them to get embodiment plans out of the way. In practice, September is a busy month for students for non-academic purposes. Between the career fair and job interviews, students have little time to dedicate to their course work. The consequence of external distractions leads to widespread procrastination. Scrambling to complete needs and metrics within a week, and jumping strait from concept design to embodiment, many teams do not have ample time to research machine elements to incorporate into their designs, and instead will submit embodiment drawings sans a coherent work plan, and without the detail necessary for the assignment to be useful construction.
Mal-preparation in front-end practices ultimately leads to a fearless group of proactive students attempting to motivate their peers. Their efforts are typically unsuccessful, since due dates do not reinforce the need to create comprehensive embodiment plans, or respond to initial design flaws.

This plot proves that intense preparation in the first 6 weeks pays off in the long run. Although chipping away at final presentations, formal reports and final drawings was encouraged from day 1, can serve as a better way to streamline students' efforts throughout the term. For instance, work can be minimized by telling students when to copy and paste (possible) written reflections for each stage (as well as necessary images and diagrams) into final report and slide deck templates. Another way to assist students in time management is to institute incremental chunks of brainstorming stages and design work that can be submitted on a weekly basis. This can be done in the form of Workshops, where students learn the skills necessary to apply knowledge from MEMS 311 to their product designs.

5 Review of EECE 402 (Chemical Engineering Senior Capstone) Structure

Finding a better way to involve each member of the team, such that their contributions build over the course of the semester, is one challenge that needs to be addressed. Another, is that teams must be given more time to reach a point of clarity so that nobody goes into the machine shop blind. This can be achieved through two separate work plan documents, where all students must input their work hours for each task.

- Primary Work Plan (Concept development through embodiment and manufacturing plan)
- Secondary Work Plan (Parts ordering through final report)

Based on the grade percentage of each assignment, assignment sub-tasks can be delegated to ensure that contribution toward group success is equitable. One method of ensuring that teams stay on track is weekly in-class assignments. This strategy is used in the capstone course for chemical engineering. In this course, in-class assignments prepare students to use the chemical process simulation program Aspen-HYSYS. Learning this program is necessary for EECE seniors to complete their final project: the AlChE design competition. The assignment varieties (in class work, first project, final project) outlined in EECE 402 can serve as potential a model for MEMS 411. Such an arrangement allows students time to develop design skills through in-class assignments and practice applying these skills on a first project of their choosing. Afterwards, all students can participate in the ASME design project. The course syllabus for EECE senior capstone project is shown in Figure 11.

Interestingly, the AlChE design problem attempted by students in EECE 402 does not actually task students with competing in the AlChE competition of their year. Rather, this problem is adapted slightly from year to year. From the start of the semester, students participate in Workshop exercises to build the skills necessary for designing a chemical engineering process using Aspen-Hysys.

Cross-team collaboration in this course is not encouraged, as teams compete to develop the most economical process, addressing the AlChE prompt.

As students develop Aspen-Hysys skills through a series of workshops, the midterm assignments expose students to product design and marketing although they dont actually engage in the design process for the midterm. Application of this course structure would of course engage students in design processes, however the division of tasks and skill-development exercises would serve to expand the repertoire of Mechanical Engineering students who may not choose to take on a project involving, say, an Arduino otherwise.

EECE 402: ChE Capstone			Dr. Moon					Commitment	
Due Date	Window for completion (between submissions)	Days into semester	% of grade	Section	Description	Class Hours	HW Hours	Per Assignment	Rate of task completion (hours/day
1/19/16	0	0			First day of classes	0	0	0	
			24%	Workshop Report					
2/8/16	20	20	3%		Workshop 1	3.78	2.52	6.3	0.315
2/15/16	7	27	3%		Workshop 2	3.78	2.52	6.3	0.9
2/22/16	5	32	3%		Workshop 3	3.78	2.52	6.3	1.26
2/29/16	7	39	3%		Workshop 4	3.78	2.52	6.3	0.9
3/7/16	7	46	3%		Workshop 5	3.78	2.52	6.3	0.9
3/28/16	19	65	3%		Midterm	3.78	2.52	6.3	0.33157895
4/4/16	5	70	3%		Workshop 6	3.78	2.52	6.3	1.26
4/11/16	5	75	3%		Workshop 7	3.78	2.52	6.3	1.26
			26%	Midterm					
1/27/16	8	8	1%		Elevator Pitch(Individual)	1.26	0.84	2.1	0.2625
3/2/16	35	43	10%		Midterm Presentation (team)	12.6	8.4	21	0.6
3/9/16	42	85	15%		Midterm Report (team)	18.9	12.6	31.5	0.75
			45%	Final Project, AIChE Design Competition					
2/17/16	29	29	4%		1st Report	5.04	3.36	8.4	0.28965517
3/30/16	42	71	9%		2nd Report	11.34	7.56	18.9	0.45
4/6/16	7	78	4%		Review on 2nd Report	5.04	3.36	8.4	1.2
4/20/16	14	92	10%		Presentation	12.6	8.4	21	1.5
5/2/16	12	104	18%		Final Report	22.68	15.12	37.8	3.15
								199.5 hours	

DAY	WS	MI	FP	SUM
0	0.315	0.2625	0.28965517	0.86715517
8	0.315	0.6	0.28965517	1.20465517
20	0.9	0.6	0.28965517	1.78965517
27	1.26	0.6	0.28965517	2.14965517
29	1.26	0.6	0.45	2.31
32	0.9	0.6	0.45	1.95
39	0.9	0.6	0.45	1.95
43	0.9	0.6	0.45	1.95
46	0.33157895	0.75	0.45	1.53157895
65	1.26	0.75	0.45	2.46
70	1.26	0.75	0.45	2.46
71	1.26	0.75	1.2	3.21
75	1.26	0.75	1.2	3.21
78	0	0.75	1.5	2.25
85	0	0.75	1.5	2.25
92	0	0	3.15	3.15
104	0	0	3.15	3.15

Figure 10: *EECE 402 Spring 2016* Ideal Workload Distribution [?]

Indicated by the three different simultaneous plots, three separate streams of assignments are indicated by Workshop Reports (WS, in class), a midterm project (MI), and a final project (FP, AlChE competition prompt). Unlike MEMS 411, the workload steadily increases over the semester and large goals are worked towards overtime. In this context, the midterm project is a presentation and report where students research the marketability of a design innovation. This design innovation does not need to pertain to Chemical Engineering, but it allows students to research and prepare design concepts, while they work towards developing the skills necessary to successfully execute the AlChE project in class. In total, the workload for this course is as follows:

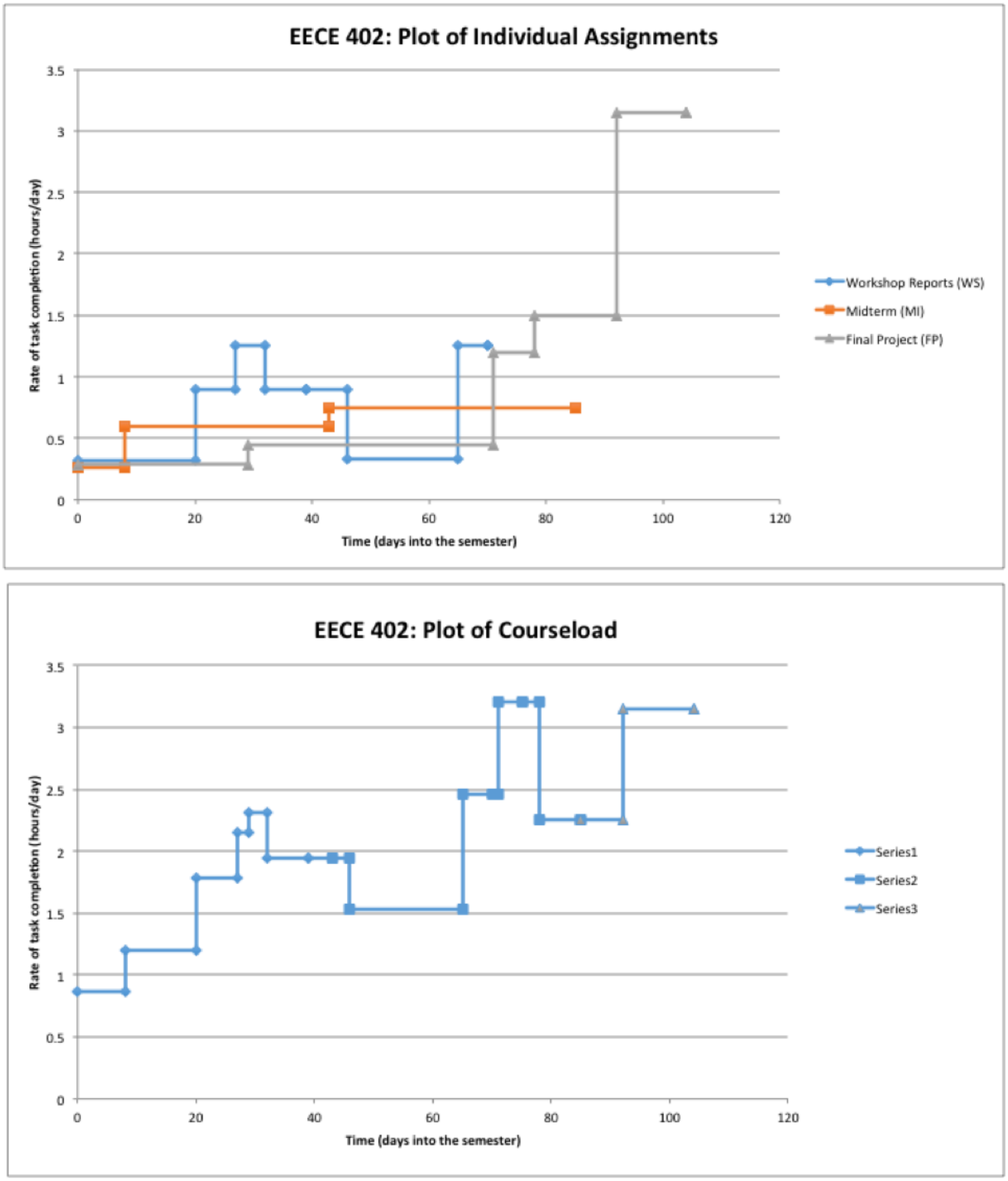


Figure 11: *EECE 402 Spring 2016* Ideal Workload Distribution [?]

A project sequence of this kind could be beneficial to MEMS 411 students, as students could gain exposure in human-centered design practices, and work towards strict criteria and challenges proposed by ASME design projects.

MEMS 411: Mechanical Engineering Design Project						Dr. Malast, Dr. Jakeila				Total Time	
"Proposed" Method										Total Time	
Due Date	Window for completion (between submissions)	Days into semester	% of grade			Section	Description	Class Hours	HW Hours	Per Assignment	Rate of task completion (hours/day
	0	0					First day of classes	0	0	0	
						MEMS 311					
4/31/2016	6	0				PR	Identification of Problem	0	0	0	0
5/3/16	4	0				MA	Resolve Favorable Environment	0	0	0	0
					weight	R & D Project					
		0				MEMS 411 - Design Iteration (3-person teams)					
		16	12%			Research				24.4521	1.52825342
				0.685%	1%	MA	Define Customer	0.8630137	0.575342	1.438356	
				0.685%	1%	RE	Enthrographic Research	0.8630137	0.575342	1.438356	
				0.685%	1%	MA	Consumer Mentality	0.8630137	0.575342	1.438356	
				0.685%	1%	PR	Speficiation of Problem to Consumer	0.8630137	0.575342	1.438356	
				0.685%	1%	DE	Specification of Product Use	0.8630137	0.575342	1.438356	
				1.370%	2%	RE	Speficiation of Existing Product	1.7260274	1.150685	2.876712	
				1.370%	2%	RE/DE	Identification of Flaws in Current Design	1.7260274	1.150685	2.876712	
				1.370%	2%	PR/DE	Identification of Problem Consumer Doesn't know they have	1.7260274	1.150685	2.876712	
				2.740%	4%	DE	Design Requirements	3.45205479	2.30137	5.753425	
				1.370%	2%	PR	Elevator Pitch	1.7260274	1.150685	2.876712	
		32	12%			Specification Study				25.8904	1.61815068
				2.740%	4%	DE	Requirement Specification	3.45205479	2.30137	5.753425	
				2.055%	3%	PT	Prototype #1: Crude "Works-Like"	2.5890411	1.726027	4.315068	
				0.685%	1%	MA	Assess Business Opportunity	0.8630137	0.575342	1.438356	
				1.370%	2%	MA, DE	Customer Review #1: Test Prototype on Target Consumer	1.7260274	1.150685	2.876712	
				1.370%	2%	AN	Annotate: Decisions Resulting from Customer Review #1	1.7260274	1.150685	2.876712	
				0.685%	1%	RE	Research Codes & Standards	0.8630137	0.575342	1.438356	
				0.685%	1%	RE	Research Existing Patents	0.8630137	0.575342	1.438356	
				2.740%	4%	AN	Annotate: Codes & Standards, Patents	3.45205479	2.30137	5.753425	
		45	10%			Refinement Stage 1				21.5753	1.65964173
				2.740%	4%	AN	Engineering Analysis #1: Proportions & Strength	3.45205479	2.30137	5.753425	
				2.740%	4%	DE	Create Concept Sketches	3.45205479	2.30137	5.753425	
				2.055%	3%	PT	Prototype #2: Crude "Works-Like"	2.5890411	1.726027	4.315068	
				1.370%	2%	MA, DE	Customer Review #2: Test Prototype on Target Consumer	1.7260274	1.150685	2.876712	
				1.370%	2%	AN	Annotate: Decisions Resulting from Customer Review #2	1.7260274	1.150685	2.876712	
		62	15%			Refinement Stage 2				31.6438	1.8614021
				2.055%	3%	AN	Engineering Analysis #2: Performance & Ergonomics	2.5890411	1.726027	4.315068	
				2.055%	3%	DE	Refine Concpet Sketches	2.5890411	1.726027	4.315068	
				4.110%	6%	DE	"Draft" Prototype #3 (Embodiment)	5.17808219	3.452055	8.630137	
				1.370%	2%	RE	Research: Materials used by Competitors	1.7260274	1.150685	2.876712	
				2.740%	4%	PT, DE	Prototype #3: 3D Printed "Model"	3.45205479	2.30137	5.753425	
				1.370%	2%	MA	Customer Review #3: Test Prototype Experience	1.7260274	1.150685	2.876712	
				1.370%	2%	AN	Annotate: Decisions Resulting from Customer Review #3	1.7260274	1.150685	2.876712	
		71	8%			Refinement Stage 3				17.2603	1.91780822
				0.685%	1%	AN	Compliance to Codes & Standards Testing	0.8630137	0.575342	1.438356	
				2.740%	4%	AN	Similarities & Differences from Existing Patents	3.45205479	2.30137	5.753425	
				2.055%	3%	DE	Adopt Design Resolution to find Novelty	2.5890411	1.726027	4.315068	
				2.740%	4%	PT, DE	Embodiment: Prototype #4 Finalized CAD document	3.45205479	2.30137	5.753425	
		83	11%			Mobilization Stage 1				23.0137	1.91780822
				4.110%	6%	PA	Manufacturing Processes Plan	5.17808219	3.452055	8.630137	
				2.740%	4%	ES	Material Expense Estimate	3.45205479	2.30137	5.753425	
				2.055%	3%	DE	Packaging Design/ Parameters (Revisit Requirement Specification, Create "Design Story")	2.5890411	1.726027	4.315068	
				0.000%		Mobilization Stage 2					
				4.110%	6%	PAT	Draft Design Patent	5.17808219	3.452055	8.630137	
				2.055%	3%	ES	Final Prototype Manufacturing Appraisal	2.5890411	1.726027	4.315068	
		100	18%			Final Product Presentation				37.3973	2.19983884
				1.370%	2%	MA	Name Your Product	1.7260274	1.150685	2.876712	
				2.740%	4%	MA	Present #1: Brochure/ Portfolio	3.45205479	2.30137	5.753425	
				4.110%	6%	PR	Present #2: Slide Deck	5.17808219	3.452055	8.630137	
				2.740%	4%	PR, MA	Present #3: Video	3.45205479	2.30137	5.753425	
				6.849%	10%	PR, DE	Present #4: Final Report	8.63013699	5.753425	14.38356	

Figure 12: ***MEMS 411 Fall 2016*** **Proposed Syllabus [?]**

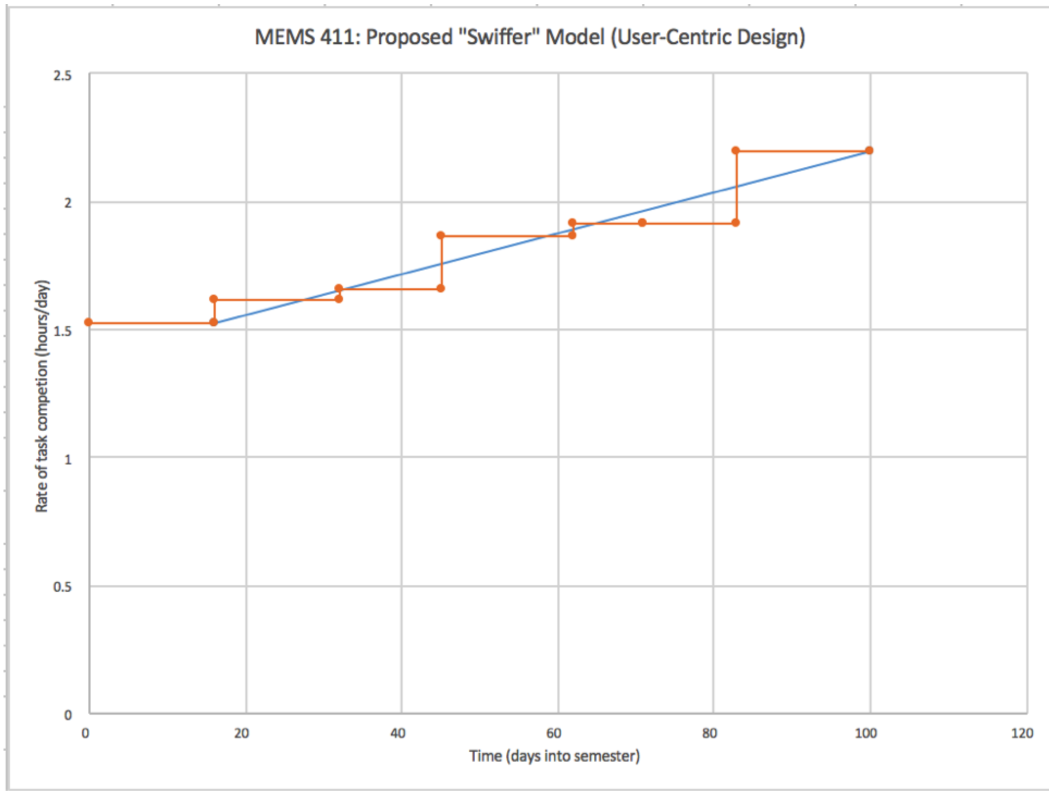


Figure 13: ***MEMS 411 Fall 2016*** **Proposed Syllabus** [?]

Working toward a gradually increasing workload or steady workload, students will benefit from increased consistency enabling teams to perform better based on an increasing time-regulated workload.

6 Proposed Solutions

6.1 Task 0: Project Suggestion Assignment

6.1.1 Student Contributions

To improve student commitment and passion for project options, this assignment will serve to collect and organize student suggestions. Implementing an organizational structure for how student ideas are presented to faculty will permit more succinct tailoring of ideas to fit the appropriate context of this course.

As described below, students will dream up a design problem and a potential solution supported by preliminary research just like the elevator pitch exercise, but this time with they create their own design prompt. In this exercise, students specify an applicable market place to convey the relevance and urgency of their particular design. Instilling a sense prospect in each idea will further engage students as they consider the possibility of creating the next great thing.

The following structure allows MEMS 411 faculty to solicit and tailor design submissions to suit course requirements of complexity and technical calculation on an elemental basis (Marketing, problem, solution, etc).

E37 MEMS 311 [Student Name Here]
Mechanical Engineering Design Project Suggestions for MEMS 411

Reading: http://www.forbes.com/sites/michaelskok/2013/06/14/4-steps-to-building-a-compelling-value-proposition/#712fdb681f2c
(if this link does not work for you, Google "4 Steps to Building a Compelling Value Proposition" by Michael Skok)

"A value proposition is a positioning statement that explains what benefit you provide for who and how you do it uniquely well. It describes your target buyer, the problem you solve, and why you're distinctly better than the alternatives."

Assignment: **Type-in responses to the following sections and complete the provided PowerPoint slide. Save assignments as Word and pptx files, respectively. Upload assignments to blackboard.**

1) Begin building your Value Proposition by brainstorming key issues you want to address in the context of MEMS 411, Mechanical Engineering Design. Use this space to think about how you want to fill-in-the-blank (items in parentheses).

   a. **For** (target customers)

   b. **Who are dissatisfied with** (the current alternative, aka your identified problem)

   c. **Our product is a** (new product description, aka your design idea)

   d. **This provides a more (or less)** (key problems with existing technology, aka your solution)

   e. **Unlike** (the product alternative, aka your competitors)

2) You have begun formulating your Value Proposition. Re-write it below to make it as concise as possible. Make sure it can be read in 30 seconds or less. Feel free to restructure sentences, but maintain the provided topic order.

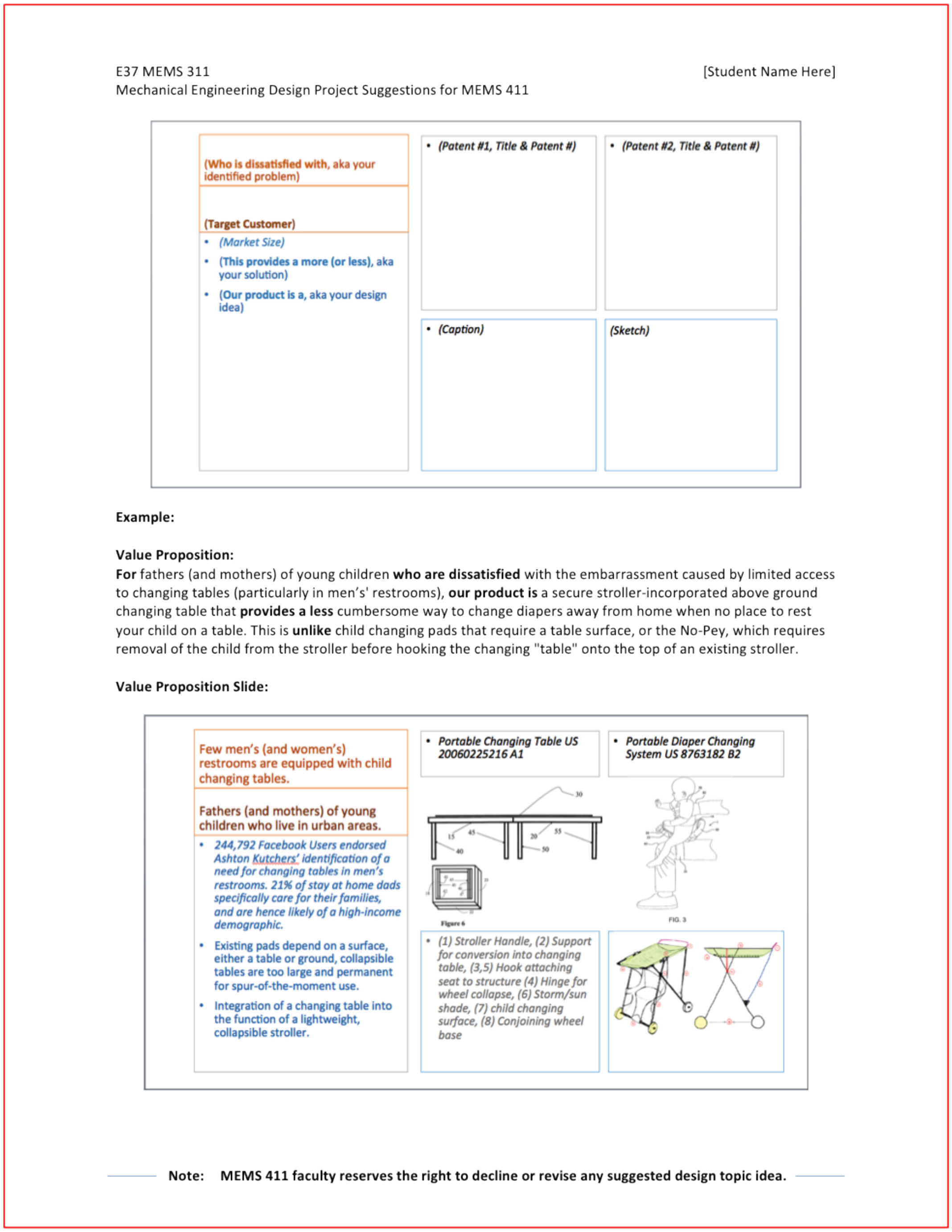
   (Final Value Proposition)

3) Using keywords from sections 1 & 2, elucidate your Value Proposition visually by using the provided PowerPoint format. Maintain standardized formatting provided. See example below.

   Encouraged but not required:
   - *Images of existing technology - provide 2 applicable patents (with patent number), if any.*
   - *Sketch the idea you have in mind, provide a caption describing potential features.*
   - *Provide a "market size" of consumers who may be interested in your product.*

Note: MEMS 411 faculty reserves the right to decline or revise any suggested design topic idea.

Figure 14: ***MEMS 311 Spring 2016*** **Final Project Assignment** [?]



E37 MEMS 311 [Student Name Here]
Mechanical Engineering Design Project Suggestions for MEMS 411

Example:

Value Proposition:
For fathers (and mothers) of young children **who are dissatisfied** with the embarrassment caused by limited access to changing tables (particularly in men's' restrooms), **our product is** a secure stroller-incorporated above ground changing table that **provides a less** cumbersome way to change diapers away from home when no place to rest your child on a table. This is **unlike** child changing pads that require a table surface, or the No-Pey, which requires removal of the child from the stroller before hooking the changing "table" onto the top of an existing stroller.

Value Proposition Slide:

Note: MEMS 411 faculty reserves the right to decline or revise any suggested design topic idea.

Figure 15: ***MEMS 311 Spring 2016*** **Final Project Example** [?]

This assignment will serve as the final assignment for MEMS 311. Over the summer, MEMS 411 faculty will review submissions.

6.1.2 Administrative Review

In large companies innovation processes can be clumped into three main sections: Front-End, New Product Development, and Commercialization [19]. Starting at the front-end, innovations can be clumped into two main categories: incremental and radical projects (defined below). Each innovation category requires different modes of preparation in order to achieve optimal project success [20].

- **Incremental Projects:** Cost reduction, improvements to existing product lines, re-positioning efforts. Opportunity identification and analysis, idea enrichment, and concept definition were found to be the most important activities for front-end success of incremental innovation.

- **Radical Projects:** Additions to existing product lines, new product lines and new-to-the-world products. In contrast, effective activity elements for radical innovation were related to understanding both existing and disruptive markets, as well as leveraging new and emerging technologies.

For the purposes of MEMS 411, radical projects are most relevant to the pursuit of project novelty over enhanced process. Professors must first consider what type of project grouping is most aligned with their mission, keeping in mind that radical and incremental projects will have drastically different project outputs and breadth of design specification. This decision is closely tied to whether product suggestions will appeal to a business or a consumer. First, a viable project suggestion must have penetrable opportunities. With the aim of discovering the best front-end practices for large companies, the Industrial Research Institute (IRI) and Process Effectiveness Network (PEN), worked together to develop a New Concept Development Model [19]. 197 large US-based companies with median annual revenues of $1.05 billion were sampled by the ROR via surveys. The model below frames new product design process. In this model, opportunity is defined as the existing gap between the current situation and the envisioned future, where in Figure 16, the wheel spokes illustrate the influencing factors of design barriers and limitations [19].

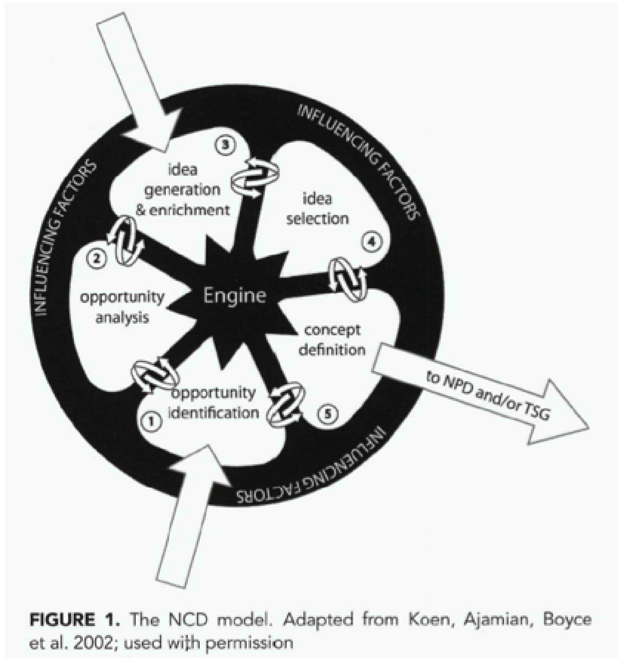


Figure 16: ***New Concept Development Model*** **Innovation wheel** [19]

At this time, professors should also consider whether the design opportunity aligns with their desired level of project difficulty, and if through this project students prototyping skills can be technically enhanced. Although a professor could overtly change the suggested design solution, influence over target market is a gentle way to sway a project's output towards course standards of MEMS faculty.Appealing to one market over another will inevitably sway the functionality of the idea.

Research on the relationship between front-end performance and ethnographic techniques [14] indicated that the success of a radical innovation is most positively related to new product orientation to a small emerging customer segment. In the appropriate market place, an novel design is capable of achieving product-to-market-fit (defined below).

Product/market-fit: being in a good market with a product that can satisfy that market. This must first be evaluated to build a successful venture, as it is a precondition for effectively scaling company marketing [28].

The new MEMS 311 end of year project suggestion assignment (shown above in Figure 15) includes completion of a Value Proposition.

By providing a clear indication of target customer, identified problem, new product description, and a proposed solution against ones competitors, this platform allows professors to elementally assess each project suggestion through a revision process that will elevate a suggestion to satisfy the scope or desired complexity of acceptable projects for MEMS 411. Ways in which student projects were amplified in the past included the change of a convertible backpacks target market to parents of young children (making this project a child carrier backpack), or creating the condition that a drone must be able to travel under water (hence creating the submarine drone).

Providing revisions on submitted slide deck files, and combining all acceptable suggestions into a conglomeration of project options, professors can distribute project options and solicit feedback from students over the summer.

6.1.3 Summarizing Questions

With the aforementioned circumstances in mind, MEMS 411 faculty must first determine whether they are open to Incremental Projects, Radical Projects, or both. Next, the following questions can be considered when assessing Project Suggestion submissions:

1. Who does the student think is their consumer?
2. Is this a viable market place?
3. What are the design limitations?
4. Is there an opportunity you envision? Does it differ from what the student presented?
5. What is the constraint or limitation you would prefer to see?
6. What skills are necessary for execution of (2)(3)?
7. What technical skills are necessary for this project?
8. What are the greatest design challenges foreseeable for this project?
9. What is the anticipated effort required for this project?
10. Is this project conducive to multiple prototypes (of varied refinement) or one?

11. What documentation is the best output for this topic?

6.2 Task 1: Project Presentation

Research revealed that in incremental innovation projects, the organizational attributes of commitment, vision, strategy, resources, and culture in senior management are most important for guiding design teams toward success [24]. Two meta-analyses of product teams also revealed that leader effectiveness, team intellect, and experience were significantly related to group success [18]. Design groups without leadership derived from senior management, in this study, struggled to gain footing. For incremental projects, the New Concept Development model wheel (figure 16) is most significantly driven by effective team leadership, which accounted for 27 % of Front End Innovation Performance, with team effectiveness accounting for 23 %, and communities representative of 20 % of team success (shown in Figure 17).

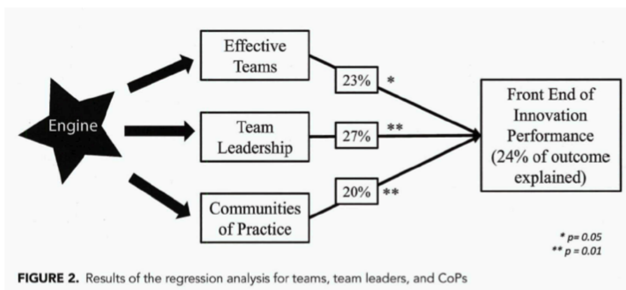


Figure 17: *New Concept Development Model* Regression Analysis of Team Performance [20]

- **Communities of Practice:** groups of people who share a common concern or passion for something they do and learn how to do it better as they interact regularly [29]
  - **Domain:** (senior design course)
  - **Community:** where members of the domain interact and learn together, interacting possibly not daily, but often
  - **Practice:** where the CoP members are practitioners, who develop a shared repertoire or resources, helpful tools, and methods [24] .

6.2.1 Team Formation

Traditionally, the community segment of MEMS 411 has been driven by project interest, but was also largely motivated by students who are familiar with each other choosing to be on a team with their peers, regardless of the project output. This tendency is understandable, since teams who specifically assemble through friendships are aware of their friends strengths, weaknesses, and assets to the team.

Effective formation of a team is something of an art form. The most successful teams strategically chose friends based on each group members unique (pre-conceived) aptitudes. Other teams are formed purely based on friendship, only to realize later, as an example, that not a single member was comfortable in the machine shop. Most teams will not be lucky enough to be stacked with all-stars, each uniquely capable in their roles. All-star teams with seemlingly limitless capability included each of the following individuals:

- The CAD/SolidWorks Jockey
- The CNC Extraordinaire
- The Math and Analysis Guru
- The Detail-Oriented Well-Versed Communicator

Mediating the challenge of navigating student skill sets without an interpersonal history requires an improved understanding of what tasks each student prefers. This additionally includes each students preferred leadership style: whether a student prefers to work under one team leader, the student prefers to be the team leader, or the student favors a rotational leadership style where each participant is equally accountable for a defined expertise or their assigned role.

While understanding these aspects about ones teammates is important to a well functioning and capable team, there is a lot of organizational legwork that students who are not the organizer may not fully grasp. Selecting a single team leader, or the natural occurrence of one person rising to the occasion, can in fact be detrimental to a team. A team leader often becomes overburdened with managerial tasks that prevent them from effectively exercising their skills. In the face of incomplete assignments, it becomes all to easy for this person to step-in, even if this exceeds the realm of their responsibility. Therefore, student roles should be paired with organizational tasks, such that delegating responsibility no longer is a task of a manager, but rather occurs as an understanding between teammates that each person has their respective obligations to the group.

One method is for students to choose a role based on what they believe they are best at. Possible roles and sub tasks are as follows:

1. Design Leader (CAD/SolidWorks Jockey)
    - Researches optimal mechanical components for applied purpose
    - Creates and leads CAD/SolidWorks work plan
    - Provides metric specification of part designs
2. Construction Manager (CNC Extraordinaire)
    - Creates manufacturing plan, including estimate of work hours to completion
    - Groups itemize procedures to expedite construction
    - Schedules, sets up and cleans up group construction times
3. Librarian, Documentation Leader (Math and Analysis Guru)
    - Performs calculations for design specification (using wire frames)
    - Creates goals and requirements for each design section
    - Manages shared files
    - consolidates images of design processes
4. Communications Director
    - Serves as primary contact between staff, target customer, Professors, and teammates
    - Keeps in contact with all group members to ensure that tasks are on-schedule
    - Responsible for assignment submissions, including fulfillment of all rubric requirements
    - Maintains and manages group Work Plan (explained below)

6.2.2 Primary Presentations

In the past, team formation stemmed from 30 second topic interest proposals in the form of an elevator pitch. Of the 20 project options, despite the multitude of project possibilities, a few projects were extremely popular. Therefore, 10-12 strong project suggestions may be ideal moving forward. The proposed structure serves to guide students toward forming teams that are based on topic interest and interest in a particular role or expertise.

Student suggested projects chosen for students to consider should be presented on the first day of class. Prior to this, each student responsible for the suggested project will be given an extended Primary Presentation template, as well as a background research study of existing patents (performed by Lauren Todd). Using this information, these students will prepare a brief presentation to the class and each Primary Presenter will indicate the skills necessary to produce their suggested topic based on the criteria indicated in the Primary Presentation Template. Any and all companies interested in soliciting the help of this course will also need to present their design projects in this format:

Primary Presentation Template

- Slide 0: Introduction and Market Viability
- Slide 1: Design Skills
- slide 2: Construction Methods
- slide 3: Mathematical Analysis and Research
- slide 4: Timeline for Design Development
- (3-5 minute time limit, depending on total number of presentations)

Each Primary presenter will be given a 3-5 minute window to describe his or her value proposition in Slide 0. Each student must provide a brief description of Project Activities in Slide 1-Slide 4. Allotted time per primary presenter will vary based on the quantity of options on the Project List. Following presentations, a reception will enable students to ask each presenter questions and express interest in a topic.

During Primary Presentations, observing students will be instructed to take note of what elements most interest them in the design projects. They will be reminded that the project activity they select will be as important, if not more important than the project topic they select.

6.2.3 Secondary Presentations

- 1. Select a Project Topic that interests you
- 2. Select one Project Activity that appeals to you (Slide 1-4 from Primary Presentation topics)
- 3. Elaborate on the (2)
- 4. Repeat for two different Project Activities, under the same Project Topic or different.
- (30 second time limit, fewer than 30 words/slide, 15 seconds on first choice, Remaining 15 seconds on back-up choices)

In the following class period, Secondary Presentations will consist of all students presenting a 30-second elevator pitch, elaborating on a three different Project Activities of interest (these can be for the same or different projects). During presentations, a scribe (Professor or TA) will fill out a spreadsheet where each students interests and contact information will be compiled and sent out to the class. In this email, students will be encouraged to form teams with partners that have a similar project interest, but a different activity interest. This organizational tool of the activities and topics that most interest each student will enable students to best formulate teams based on area of expertise. Since students are still responsible for forming their own teams, they will be able to join with friends. However, students interested in branching out will be able to do so more strategically and organically than before.

6.3 Task 2: Project Selection

According to the NCP model, 53 % of a teams ability to product a successful concept is due to organizational attributes, including senior management commitment, vision, and strategy [20]. Team effectiveness can be managed by some of the methods outlined by the constructs for teams and collaboration [20]. When formulating teams, it is important that people are placed according to the following similarities:

- Commitment to project (effective teams)
- Interest in spending excess of time to make it just right (effective teams)
- Similar desired weekly work-hour input
- Leadership interest (preference to devote at least 25(percent) of time to CoP)
- Interest in management of action items

Organizational attributes are often a difficult workload to delegate, since the benefits of a well lead team are not directly rewarded by grade. However, low scoring team most likely suffered due to failed leadership. For this reason, one member per team who has leadership interest should be selected. Having one team member devote at least 25 % of his or her time to advancing the CoP is one way to help teams thrive. This particular leadership position can be rewarded points by recording whether or not weekly action items are sent out, communications with interviewees and professors are managed, and whether or not the team is kept on schedule.

Significant constructs for teams and collaboration are shown in Figure 18.

TABLE 2. Constructs for teams and collaboration

Construct	Variables	Cronbach's Alpha*	AVE**
Performance in the Front End	The degree to which products in the front end are able to 1) generate sustainable competitive advantage, 2) deliver on front-end strategic objectives, and 3) deliver a front-end portfolio that is balanced—across types (product lines, technology platforms, new-to-the-world products), markets, and technologies, and with respect to long-term vs. short-term outcomes and risk. (3-item construct)	0.79	0.62
Effective Teams	The degree to which team members 1) are committed to their projects and 2) spend time and effort beyond job requirements. (2-item construct)	0.80	0.62
Team Leadership	The degree to which team leaders 1) have recognized leadership experience and credibility throughout the organization, 2) assure team performance exceeds expectations, and 3) enable and support commitment of all team members. (3-item construct)	0.82	0.68
Communities of Practice (CoPs)	The degree to which the organization 1) encourages and supports CoPs, providing each community 2) a budget and 3) a coordinator who dedicates at least 25 percent of his or her time to the CoP. (3-item construct)	0.79	0.66

* Cronbach's alpha is a measure of the internal consistency of a multi-item scale.
** Average variance extracted (AVE) measures the amount of variance captured by the construct in relation to the amount of variance due to measurement error.

Figure 18: *New Concept Development Model* Constructs for Teams and Collaboration [20]

6.4 Work Plan

A comprehensive team Work Plan can be implemented in a Gantt-style similar that used to assign required work hours based on syllabus-indicated assignment weight. Each assignment can be broken down into sub tasks that allow students to delegate and plan ample time for subsection completion. This Gantt chart can be "dynamic" in the sense that if any unfulfilled duty is shifted to from one team member to another, spreadsheet work hour balances can be used to delegate efforts in pursuit of balanced contribution. More fluid exchanges for sub task management will help teams handle scheduling barriers to maintain progress, even when a teammate is delayed.

6.4.1 Problem Identification

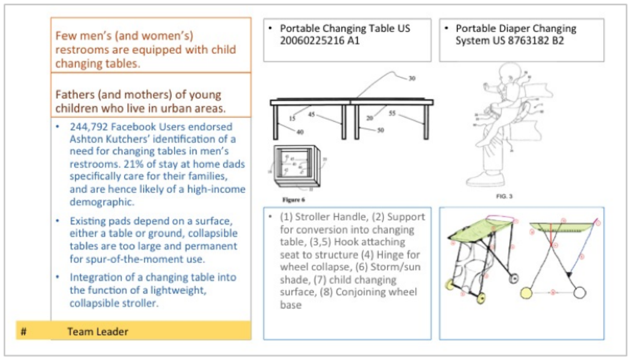


Figure 19: *MEMS 311 Spring 2016* Final Project Assignment [?]

Beginning with an identified problem, a bare-bones design solution outlined by Value Proposition assignment (shown above in Figure 19) and the Primary Presenter's informational presentation, a project team must first refine the suggested design project topic by preparing a more in-depth product or itemize research of competing products, existing technology, and the present marketplace landscape.

Effective research begins with mutual understanding of what problem the team is setting out to solve. In accordance to the New Concept Development model, a Problem Statement should simply and eloquently explain all identifiable aspects of the issue at hand.

As an essential first-step to guiding and focusing a teams' efforts throughout the semester, problem identification exercise can be completed as a for-credit and in-class exercise (immediately following team formation).

Starting with what will likely be a big picture issue, teams will need to identify subtopics that are correlated to their guiding problem. Breaking down an identified problem into elements will allow teams to more effectively identify how to respond to this problem.

Listed below is a possible format for this exercise:

1. (5 minutes) As a group, restate the identified problem (from the Value proposition). Get out a recording device and toss out key words and issues associated with this problem.

2. (7 minutes) As a group, re-listen to the conversation, and in a word document, have one teammate type out any words that seems relevant to your problem. This list should be no longer than 20 words.

3. (3 minutes) As a group, review these ”problem identifiers” and group like-identifiers into groupings. The number of groupings created will be based on the number of students in the team. Each team member is to select and write down one grouping of correlated ”problem identifiers”

4. (5 minutes) For each problem identifier grouping, take 5 minutes to discuss possible solutions, and designs that remedy said issues already. Designs that similarly respond to said problem can be far more difficult implement than designs for the product your are actually creating, but can serve as an example for creating a design concept that responds to said issues.

5. (15 minutes) The final task is creating a group problem statement. From the original value proposition, identified problems were stated briefly in a phrase. The output of this exercise should be at least one completed, detailed sentence about what your team is setting out to do.

Although this exercise simplistic, the output of a concentrated project purpose will help guide team research efforts, as as well as allow them to re-focus on their problem after user interviews or sizing up the competition that may cause them to inadvertently abandon the problem they set out to solve.
More importantly, group members will leave with a specific area of research they are responsible for. This facilitates cross comparisons of information from a variety of sources withn the team.

1. (5 minutes) Teams will brainstorm who this issue is relevant to, coming up with 3-4 distinct groupings of consumers (either businesses or primary consumers, depending on topic). Each student will be assigned one target market in addition to their existing list of problems and associated solutions.

Figure 20: *Problem Identification* Background Research Study [?]

The presentation format indicated in 20 can either be completed in an Adobe Illustrator document or can be similarly organized in a slide deck. With each team member focusing on a specific aspect of their identified problem, at the following in-class meeting, students can present and review each others' findings. Completion of this exercise will provide students the background information necessary for further analysis of existing technology such that each group can revisit their original problem statement and refine it in further detail.

At this stage, a team is now prepared to create a precise problem statement paragraph, which will include indication of customer segmentation (various target markets and how large they are), insights about what their consumer wants and why this problem and solution is relevant to the consumer.

Based on competitor product specifications, each team can begin to assess what metrics are most important to them (that their competitors already successfully achieve), and in what ways they want to improve each design with functional attributes. While team members will have an idea of how they think their design topic can be resolved, it is important to first interact with their target customer.

6.4.2 Enthograhic Research

When Craig Wynett, the inventor of the Swiffer, identified in 1994 that there had to be a better way to clean the floor, his first move was pooling a team new venture researchers from the hard surfaces and papers division at Proctor and Gamble (Chain of Innovation). Design anthropologists conducted what is called Enthographich research, to examine how people clean the kitchen floor, why they clean it the way they do, and if anything cuts deeper into the human experience of cleaning the floor.

Enthographic Research: Focuses on how people make sense of the world by collecting information to understand things about a user who might not be able to communicate topics directly [4].

What they learned, is that people had a strong emotional connection to a clean home. Often, when conducting research, Proctor and Gamble's test subjects would in fact clean their floor prior to the team of P&G researchers arriving at their home - even though they were there to watch subjects clean their floor! Through Wynett's teams' research, a baseline process was produced: move furniture, sweep loose dirt, locate components, mix solution, prepare mop, etc. [17]. Research including process time and method revealed to P&G researchers that mop users were spending more time preparing their mops than cleaning their floor. With this understanding, new mop designs were produced and tested, before a final metric was applied to the arrangement: this mop would fit in a box on a shelf. As such, it was easier to merchandise this particular variety of mop, since it did not require vertical space like traditional mops and brooms [17].

Technically simple, the design of the Swiffer was created by a process titled [21] probe and learn, where multiple iteration cycles are employed by companies that release, redesign and again test their product success in the market place. Their method is advocated by Raynor (2003) and OConnor et al. (2008) for better understanding the features and benefits of an emerging market. For instance, this "probe and learn" tactic was used by MIT when they were looking for a way to best release a new technology in the market. As such, MIT tasked eight entrepreneurs with individual market expertise to design a product that successfully utilizes their achieved technology and achieves ideal product to market fit [22] [21].

Discovering the less obvious necessities and interests of a teams' identified consumer can be facilitated through enthographic research tactics, listed below:

Enthgraphic Consumer Interview Tactics [4]

- Ask interviewee first to tell you about how they do something, then ask if they can show you how something is done. On your own, assess the cognitive level of the interviewee, based on whether their verbal response matches their physcial demonstration. This strategy is called Trianglating.

- Look for "cultural probes" including: Activities, Environments, Interactions, Objects, and Users (AEIOU), if possible obtain photos.

- Ask interviewees to draw relationship maps of how they use things, or the process in which they approach a task in daily life.

- Play out scenarios of interest to cultivate a response from interviewee.

- Document testimonies with photos, voice recordings, and video clips if possible.

- When interviewees go off topic, thank them for their responses and ”circle back” the conversation to your desired topic and or questions.
- Show interviewee photos you have taken and of obejcts around them to solicit feedback.
- Make sure your that in your interview you obtain three points of view: direct conversation, response observation, and participatory activities.

1. **Needs:** Metrics and design scoring favors the design that attempts to do everything - this is rooted in the issue of having an overly broad problem identification - problem identification therefore must be ultra specific from the start.
2. **Background Research:** Research is prepared to determine what is protected by IP, but never do students research the real market value of one design over another.

6.4.3 Dynamic Work Plan

6.5 Task 3: Conceptual Design and Specification

The beginning stages of concept sketching are limited by students abilities to express their ideas to their teams. At the earliest stages of a design, the high resolution and metric specificity typical of digital design platforms can actually hinder the flow of ideas and the natural evolution of a sketched design. It is therefore necessary for MEMS 411 to create exercises that focus on developing the components of a design in a more elemental way. Jumping into sketches that depict a completed assembly of many parts will be difficult for students without design sketching experience. Rather, if teams can move more quickly to digital platforms by focusing on sketching subsections of corresponding joints, students will be prepared to move past the necessity for concept sketches more quickly.

More importantly, detailed documentation is essential for groups to maintain a comprehensive understanding of each separate part’s status. Diary-like documentation can be extremely beneficial to students. Although Slack was the intended platform, if group members are inconsistent with reporting, this method of communication fails.

6.5.1 Enthographic Research Study

6.5.2 Concept Design Bids

Sketch concept drawings that service ( ) of the keywords, but with a dominant focus on 3 keywords.

- Concept (Rough Sketches of shape)
  - Front
  - Side
  - Top
  - Orthonormal
  - Defining Features (4)
- Motion Diagram
  - Identify Degrees of Freedom
  - Sketch How Object Moves/Adjusts
- Total Concept
  - Phase
  - Sentence
  - Paragraph
- Each Element
  - Phrase
- Estimate Material Expenditures
  - # Purchased Joints
  - # 3D Printed Joints
  - # Fabricated Joints

- Fasteners
- Rigid Bolts
- Critical Elements
- Interfaces
- Electronics
- Control Systems

- Estimate Time Expenditures
- Identify Critical Values for Calculation

6.5.3 Concept Selection

As groups explore the many possibilities of a design, their exploration often results in a laundry list of additional features. With each feature comes specific facets can be extremely distracting if the function does not service the overall design goal. Unfortunately, existing methods for project scoring tend to favor designs that "do it all" since these designs will receive the most points for incorporation of all desired metrics.

For this reason, teams must be extremely judicious about what functions are important to their team, their problem, and their design goals. Ensuring that user metrics (used to compare and gauge each concept) properly reflect the overarching objectives of the team will enable teams to make the most of the design scoring exercise.

- (Solution) Team generates a brief cost estimate of both labor and materials for each concept design.

6.6 Task 4: Embodiment and Fabrication Plan

6.7 Manufacturing Process Plan

- (Solution) Team need an assignment that focuses on how its' made - this will provide less confusion in the machine shop.

7 Analysis

7.1 Applications to MOOC coursework

7.2 Digitization of process

7.3 Future Refinement

7.4 Student Grade Assessment

8 Conclusion

Creation of a tool to be used by credential seekers of design coursework will enable students and credential seekers alike to respond to elucidated processes in order to create an advanced manufacturing process for design implementation. In the proposed course structure, students are encouraged to use 3D-printed and CNC-d manufacturing methods in order to prepare a methodical representation of a proposed radical design innovation. Created in an effort to instruct strategic drawing and design skills, this design process links group operations around the centerfold of new product design elements. Although not fully described in this report, comparative exercises between what technology exists, what competitors exist and overarching consumer needs and design goals will be inspected on an elemental basis first, before full concept assemblies are developed.

Creating a framework for design teams to collaborate and advance designs can evolve into a platform that enables detailed assignment postings to be completed remotely between group mates. Such a structure would be extremely appealing to MOOC learners interested in seeking credentials that describe their abilities to think creatively in the context of Mechanical Design Engineering.

Assignments of this kind will be graded upon completion and final output, such that accuracy of preliminary tasks can be verified by final performance of design goals specified by a course or individual project.

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