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Multi-Disciplinary Capstone Project on Self-Replicating 3-D Printer

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Dr. Paul Robert Yearling, Indiana University - Purdue University, Indianapolis

Paul Yearling Education: PhD. Major: Mechanical Engineering, Minor: Applied Mathematics Professional Engineer License Certifications: Lean Six Sigma Black Belt Current Position: Associate Chair Engineering Technology and Mechanical Engineering Technology Program Director

Industrial Experience

Over 20 years of industrial experience initially as a Royal Naval Dockyard indentured craftsman machinist and Design Draftsman and project manager on Leander class Steam Turbine Naval frigates and diesel electric submarines. Most recently includes 12 years in Research and Development and Lean Six Sigma process improvement experience troubleshooting process issues in the Paper, Chemical, and Converting Industries.

Mr. Jacob Allen Smith, Indiana University - Purdue University, Indianapolis

During the completion of this project I was a student of IUPUI. I worked on the Electrical Engineering Technology side of the project in conjunction with another student. I also served as the main Project Manager for the student groups and to the Project Heads Elaine Cooney and Paul Yearling. Both stated that my management skills on the project were incremental to the completion of the project in a timely manner.

Multi-Disciplinary Capstone Project on Self-Replicating 3-d Printer

Abstract

This paper explores the dynamics of a multi-semester multi-disciplinary team approach applied within a traditional senior capstone project that involves strong design and manufacturing components. In addition, the logistics of running a successful senior project will be discussed along with the associated problems of organization within a multi-program environment. The key drivers and motivators behind this paper are, most importantly, that multi-disciplinary teams are very common in industry and that our industrial advisory boards for Electrical Engineering Technology (EET) and Mechanical Engineering Technology (MET) suggested that we do more multi-disciplinary projects. Furthermore, this multi-disciplinary team approach will satisfy the proposed ABET/ETAC outcomes for 2016. The Proposed Revisions to the Program Criteria for Mechanical Engineering Technology and Similarly Named Programs ABET/ETAC outcomes say "The capstone experience, ideally multidisciplinary in nature, must be project based and include formal design, implementation and test processes." (emphasis added)

Faculty searched for a technology that would allow both EET and MET students to contribute equally to the success of the project, and decided upon additive manufacturing. Students have been exposed extensively through formal course material covering 3D printing technology and would be familiar with the operation of 3D printers in general. Therefore, it was reasoned a familiarity with the project goal of designing and constructing a self-replicating 3D printer would give students more confidence in tackling the difficult task of managing an extended project over both the design and manufacture phases, and mastering effective communicate across disciplines.

The student team organization mirrors current industry standard operating procedures. First, the team is multidisciplinary, including EET students with programing and circuits skills and MET students with CAD, design, mechanical analysis skills. All students must demonstrate project process skills, utilizing current design for six-sigma procedures. The students learn a standard set of tools to manage the project, as well as synthesize those tools with their discipline specific knowledge.

Background

The original 3D Printing Technology was based on fused deposition modeling (FDM) technology, developed in the 1980's and first commercialized by Stratasys in the 1990s. The original concept of FDM, based on existing hot-melt gluing technology, was to deposit a thin layer of material onto a build table slowly constructing the desired component layer by layer. This paper is concerned with the design, manufacture, and testing of an open source FDM desktop machine using a single thread of acrylonitrile butadiene styrene (ABS) material.

Commercially available FDM 3-D printers have a wider selection of print material, for example polycarbonate (PC), polylactic acid (PLA), high density polyethylene (HDPE), polyphenylsuffine (PPSU), and high impact polystyrene (HIPS) to list just a few . In addition, many commercial machines use a water soluble wax or a very brittle material such as polyphenylsulfone (PPSF) as a substrate support in the building process.

FDM modeling produces components by extruding small beads of molten material (ABS) that harden to form individual layers. The material is typically a filament that is unwound from a coil and force fed into the printer head. Within the printer head the filament is passed through simple nozzle that is heated to a temperature sufficient to melt the filament. The resulting molten material is then extruded through a nozzle orifice, providing the desired size characteristic, and onto the build table. Stepper motors are utilized to adjust the distance and location between the build table and nozzle thereby controlling the deposition rate and location as the component is building. To increase the versatility of FDM a second support material is often utilized in commercial 3D printers that prevent distortion in the building process.

Fortunately, for the student design project, there is now a large amount of open source material that can be easily utilized and modified particularly based on the self-replicating printer "RepRap" project format. The RepRap 3-D Printer projects typically use FDM technology using ABS material and represents the best choice for a first time STEM student based project. For this project students were limited to the following RepRap designs: Wallace, RepRap Tricolor, Prusa Mendel, Original Mendel, MendelMax, and Huxley designs. Students were encouraged to redesign the standard design to meet the specifications for the project.

Capstone Project Specifications

This project utilized a multidisciplinary senior capstone group of mechanical engineering technology and electrical engineering technology students tasked with the design, implementation, and testing of a 3-D printer based on specification requirements. The scope of the project was selected to simulate a typical industrial design and build project. The mechanical engineering technology students were divided into separate design and build groups, since their capstone course was a three credit, one semester course, while the EET students had two semesters to complete their work.

It was explained to the student groups that they work for a 3-D Printer company tasked with the design and manufacture of a low cost desktop FDM 3-D Printer to equal or exceed a competitive design represented by the XYZ Da Vinci 1.0 3-D Printer. As part of the project scoping process the design team produced a list of design specifications as shown in Figure1.

In addition, the design team performed a "state of the technology assessment" and arrived at a list of desirable attributes for their new design:

- Fusion temperature is important – provide heated build platform
- Air flow and temperature around build platform is important – enclose and regulate air flow
- Printing time – assess nozzle diameter and allow for adjustable fusion temperature

- Open Source – a good selling point with other student groups

Cost	Approximately 600$
Printing Area	(7.8"x 7.8" x 7.8")
Printer Size	(18.4" x 20" x 22")
Resolution	.1mm~.4mm
Speed	.3 mm/s
File Type	.stl/XYZ Format
Material Type	ABS
Nozzle Size	0.4mm (Single Nozzle)

Figure 1: The design team's assessment of the Da Vinci 1.0 3-D printer specifications

Student Outcomes

Capstone projects are a hallmark of Engineering Technology curriculum. Almost all of the ETAC/ABET student outcomes[i] ("a through k") can be assessed during capstone experience, but this project focuses on five:

> c. an ability to conduct standard tests and measurements; to conduct, analyze, and interpret experiments; and to apply experimental results to improve processes;
>
> d. an ability to design systems, components, or processes for broadly-defined engineering technology problems appropriate to program educational objectives;
>
> e. an ability to function effectively as a member or leader on a technical team;
>
> f. an ability to identify, analyze, and solve broadly-defined engineering technology problems;
>
> k. a commitment to quality, timeliness, and continuous improvement.

Another consideration of this project is the program specific requirement for Mechanical Engineering Technology which states "The capstone experience, *ideally multidisciplinary in nature*, must be project based and include formal design, implementation and test processes." (Emphasis added.)

This specific capstone project lent itself to demonstrating these outcomes. Because the original charge given to the students was intentionally vague ("build a table top 3d printer") it supplied them with an appropriately "broadly-defined" problem to identify, analyze and solve as required in outcome f. For outcome d, students had to *design a system* incorporating both electrical and mechanical subsystems. Furthermore, to meet the recommendation for MET capstone experience is the project should ideally be multidisciplinary in nature, must be project based and include formal design, implementation and test processes. Because of the program curriculum plans, the EET students were involved in the project for two semesters. The MET students had a one semester project course; this enabled one group of MET students to design the mechanical system, document their work, and pass it on to a second team for implementation. This was considered a positive based on what is typical in industry, where engineering groups are constantly interfacing. The project management skills and Design for Six-sigma methodology required to coordinate three different semester syllabi (two MET capstone one-semester classes and one EET capstone year) tested all the students' commitment to quality, timeliness and continuous improvement per outcome k. Over the course of the year-long project, six MET and two EET students were team members. The students took leadership on different aspects of the project, so each of them could demonstrate outcome e, the ability to function effectively on a technical team. The ability to conduct tests, interpret results and improve processes (outcome c) was demonstrated during the proto-typing and redesign stages of the project. Privacy rules prevent the authors from including specific assessments of the students' work.

To assess the students' abilities to meet the outcomes, a collection of rubrics were used. Figure 2 shows the project design rubric used for all EET senior projects at our institution. It assesses students' abilities to identify a problem, design a system, and manage the project (outcomes d, f, and k). This project scored well above the average of other senior projects. This can be attributed to the design methodology recommended by the faculty and embraced by the students for this project to manage the complexities far beyond what the students had previously experienced.

The Critical Thinking Rubric shown in figure 3 was used to evaluate the students' ability to solve the problems identified during testing and improve the system. This rubric was developed to assess students' critical thinking during an engineering project (as compared to other critical thinking rubrics which look at students' writing). It specifically looks for the ability to parse through various solutions and select the best solution within the given constraints – something required to "to apply experimental results to improve processes" as required in outcome c.

There are many teamwork rubrics available. Figure 4 shows the VALUE rubric developed by the Association of American Colleges and Universities. This meta-rubric was created by a team of faculty members by compiling many teamwork rubrics used at the post-secondary level from across the country. Because of its wide acceptance at a variety of institutions, it is a good choice for assessing individual students' abilities to function on multidisciplinary teams. Since this project was so successful, it is no surprise that most of the students on this project performed very well as team members. Only two students performed at less than the "capstone" level on most of the performance indicators. Figure 5 shows a group dynamics rubric developed by Dr. Barbara Christe to assess the performance of an entire team – as a group. The student teams contributing to this project exceeded most expectations.

ENT Design Project Assessment Rubric
Used to evaluate ABET items d, f & k:

- an ability to design systems, components, or processes for broadly-defined engineering technology problems appropriate to program educational objectives;
- an ability to identify, analyze, and solve broadly-defined engineering technology problems;
- a commitment to quality, timeliness, and continuous improvement.

	Excellent	*Average*	*Poor*
Identification of Problem or Definition of Project	Clear & complete ID of design goals & objectives	Adequate ID of problem; any lack of specifics does not impair solution or design	Insufficient ID of problem; inadequately id's objectives
Technical design	Exceeds specs if appropriate; meets specs with efficient design	Meets nearly all specs	Missing significant specs
Complexity of project / design	Exceeds typical technical complexity for course level	Meets typical technical complexity for course level	Below typical technical complexity for course level
Appropriate choice & use of resources (e.g. computer apps, internet sources, lab equipment)	Innovative selection of resources; expert use	Appropriate resources used (such as demonstrated in class); resources limited to faculty-provided materials/tools	Inadequate use of suggested resources.
Time Management	Identified plan/ timeline & worked to it; consistently met deadlines	Goals accomplished; most milestones met; some schedule defined; inconsistent use of time; misses some deadlines despite reasonable effort	Missed significant milestones or project not completed
Information management: Log book, status reports, documentation	Detailed, appropriate and timely entries; collected & distributed to appropriate parties	Adequate entries in journal or log book; only critical data/information collected & distributed	Insufficient data collection / recording; existing documentation not shared/utilized
Conclusions & result interpretation	Obtained & adequately interpreted meaningful results with appropriate, insightful conclusions	Produced some results, but struggled with interpretation or lacked sufficient support for their conclusions	Generated few results with little meaningful interpretation; conclusions are absent, wrong, trivial or unsubstantiated.

Figure 2: Design Project Rubric

Critical Thinking Rubric – School of Engineering & Technology, IUPUI

	Beginning	Developing	Competent	Accomplished
Defining the Problem	**Indiscriminate** Takes problem as stated without regard to relevance. (repeat what is "true but not useful")	**Obvious** Determines what is relevant & what is not	**Complete** Gives voice to what other information is needed to solve problem	**Complex** Identifies and clearly states both the main question and subsidiary, embedded, or implicit aspects of the question
Proposing Multiple methods of Solution	**Singular** Names a single solution, position, or perspective, often inaccurately, or fails to present a solution, position or perspective	**Dualistic** Identifies simple solutions, over-simplified positions, or perspectives with minor inaccuracies	**Multiplistic** Describes two or more solutions, positions, or perspectives accurately	**Balanced** Explains—accurately and thoroughly—multiple solutions, positions, or perspectives that balance opposing points of view
Selecting the Most Appropriate Method	**Inappropriate** Provides a solution that does not meet the specifications required	**Reasonable** Presents a reasonable solution, but does not justify or clearly articulate that solution. No discussion of alternate approaches included.	**Relevant** Clearly articulates design of solution. Some discussion of basis in data and/or theory is present, but not thorough. Provides some justification for approach, but does not acknowledge that other possibilities are feasible	**Insightful** Clearly articulates design of solution, and draws on data and/or theoretical basis, as appropriate. Acknowledges that other approaches may be feasible, and provides justification for the method chosen
Applying Method to Generate Results	**Inaccurate** Labels formulas, procedures, principles, or themes inappropriately or inaccurately, or omits them	**Appropriate** Uses appropriate formulas, procedures, principles, or themes with minor inaccuracies	**Accurate** Applies formulas, procedures, principles, or themes appropriately and accurately in familiar contexts	**Thorough** Employs formulas, procedures, principles, or themes accurately, appropriately and/or creatively in new contexts
Conclusions and Evaluation	**Illogical** Attempts a conclusion or evaluation that is illogical or inconsistent with evidence presented, or omits a conclusion or solution altogether	**Reasonable** Presents abbreviated or simple conclusions that are mostly consistent with evidence presented, with minor inconsistencies or omissions	**Logical** Clearly states and discusses conclusions. Organizes a conclusion or solution that is complete, logical, and consistent with evidence presented	**Perceptive** Clearly states and discusses conclusions. Considers implications and consequences of the conclusion in context, relative to assumptions, and supporting evidence. Provides reflective thought with regards to the assertions

EMC & KDA 11/11/2008

Figure 3: Critical Thinking Rubric - for problem solving[ii]

TEAMWORK VALUE RUBRIC

for more information, please contact value@aacu.org

Definition

Teamwork is behaviors under the control of individual team members (effort they put into team tasks, their manner of interacting with others on team, and the quantity and quality of contributions they make to team discussions.)

Evaluators are encouraged to assign a zero to any work sample or collection of work that does not meet benchmark (cell one) level performance.

	Capstone 4	Milestones 3	 2	Benchmark 1
Contributes to Team Meetings	Helps the team move forward by articulating the merits of alternative ideas or proposals.	Offers alternative solutions or courses of action that build on the ideas of others.	Offers new suggestions to advance the work of the group.	Shares ideas but does not advance the work of the group.
Facilitates the Contributions of Team Members	Engages team members in ways that facilitate their contributions to meetings by both constructively building upon or synthesizing the contributions of others as well as noticing when someone is not participating and inviting them to engage.	Engages team members in ways that facilitate their contributions to meetings by constructively building upon or synthesizing the contributions of others.	Engages team members in ways that facilitate their contributions to meetings by restating the views of other team members and/or asking questions for clarification.	Engages team members by taking turns and listening to others without interrupting.
Individual Contributions Outside of Team Meetings	Completes all assigned tasks by deadline; work accomplished is thorough, comprehensive, and advances the project. Proactively helps other team members complete their assigned tasks to a similar level of excellence.	Completes all assigned tasks by deadline; work accomplished is thorough, comprehensive, and advances the project.	Completes all assigned tasks by deadline; work accomplished advances the project.	Completes all assigned tasks by deadline.
Fosters Constructive Team Climate	Supports a constructive team climate by doing all of the following: • Treats team members respectfully by being polite and constructive in communication. • Uses positive vocal or written tone, facial expressions, and/or body language to convey a positive attitude about the team and its work. • Motivates teammates by expressing confidence about the importance of the task and the team's ability to accomplish it. • Provides assistance and/or encouragement to team members.	Supports a constructive team climate by doing any three of the following: • Treats team members respectfully by being polite and constructive in communication. • Uses positive vocal or written tone, facial expressions, and/or body language to convey a positive attitude about the team and its work. • Motivates teammates by expressing confidence about the importance of the task and the team's ability to accomplish it. • Provides assistance and/or encouragement to team members.	Supports a constructive team climate by doing any two of the following: • Treats team members respectfully by being polite and constructive in communication. • Uses positive vocal or written tone, facial expressions, and/or body language to convey a positive attitude about the team and its work. • Motivates teammates by expressing confidence about the importance of the task and the team's ability to accomplish it. • Provides assistance and/or encouragement to team members.	Supports a constructive team climate by doing any one of the following: • Treats team members respectfully by being polite and constructive in communication. • Uses positive vocal or written tone, facial expressions, and/or body language to convey a positive attitude about the team and its work. • Motivates teammates by expressing confidence about the importance of the task and the team's ability to accomplish it. • Provides assistance and/or encouragement to team members.
Responds to Conflict	Addresses destructive conflict directly and constructively, helping to manage/resolve it in a way that strengthens overall team cohesiveness and future effectiveness.	Identifies and acknowledges conflict and stays engaged with it.	Redirecting focus toward common ground, toward task at hand (away from conflict).	Passively accepts alternate viewpoints/ideas/opinions.

Figure 4: Teamwork Rubric for individual students[iii]

Group Dynamics	*Exceeds expectations*	*Meets most expectations*	*Meets some expectations*	*Efforts fall below expectations*
Contributions (quality/management of quality	**All** members routinely contribute quality & useful ideas and information; the team evaluates all ideas and uses only the best.	Most members routinely contribute ideas and information; the team evaluates and incorporates most ideas that are appropriate	Some members contribute ideas & information; not all ideas are useful; the team as a whole adequately integrates the ideas presented	Internal conflicts results in team failing to achieve projects goals
Division of labor (equality/quantity)	All members make significant contributions & are accountable to complete assigned tasks	Progress is satisfactory, the workload is generally evenly divided	Progress is satisfactory, but unequal workload is observed	Serious problems due to unequal workload
Communication (within the team)	Consistent communication throughout project; insightful use of real and virtual meetings: meetings are productive	Communication within meetings is generally productive and collaborative. Voices are generally heard.	Adequate number of meetings (real or virtual) however communication is not shared and some voices are not heard.	Inadequate meetings and communications breakdowns are common
Professional conduct	All team members consistently behave in a professional manner (show up for meetings prepared and on time, treat other team members with courtesy & respect) & seek outside advise if team is not productive	Team members usually behave in a professional manner and are receptive to correction by other team members when unprofessional conduct is noted	Team members usually behave in a professional manner but at least one group member is NOT receptive to correction by other team members when unprofessional conduct is noted	Team members frequently fail to behave in a professional manner: team does not seek outside help
Group discipline	Stays focused on task; finds solutions as problems are encountered. Uses sound principles of inquiry when analyzing problems & seeking solutions.	Focus to complete task is maintained; some problems are discounted until a later time	Focus to complete task is sometimes lost; some off-topic discussion or actions take place; some problems are ignored	Totally lacks focus; problems are discounted; team does not take responsibility for failures of the group
Overall group collaboration	Synergy	Majority of team members willingly participate; team functions adequately	Distribution of effort is uneven, some group members carry non-performing group members	Everyone going their own way

Figure 5: Group teamwork rubric by Dr. Barbara Christe

Design Methodology in Action

As described previously the methodology chosen for this project was based on the Design for Six-sigma (DFSS) Define, Measure, Analyze, Design and Verify protocol as used in the manufacturing industry.

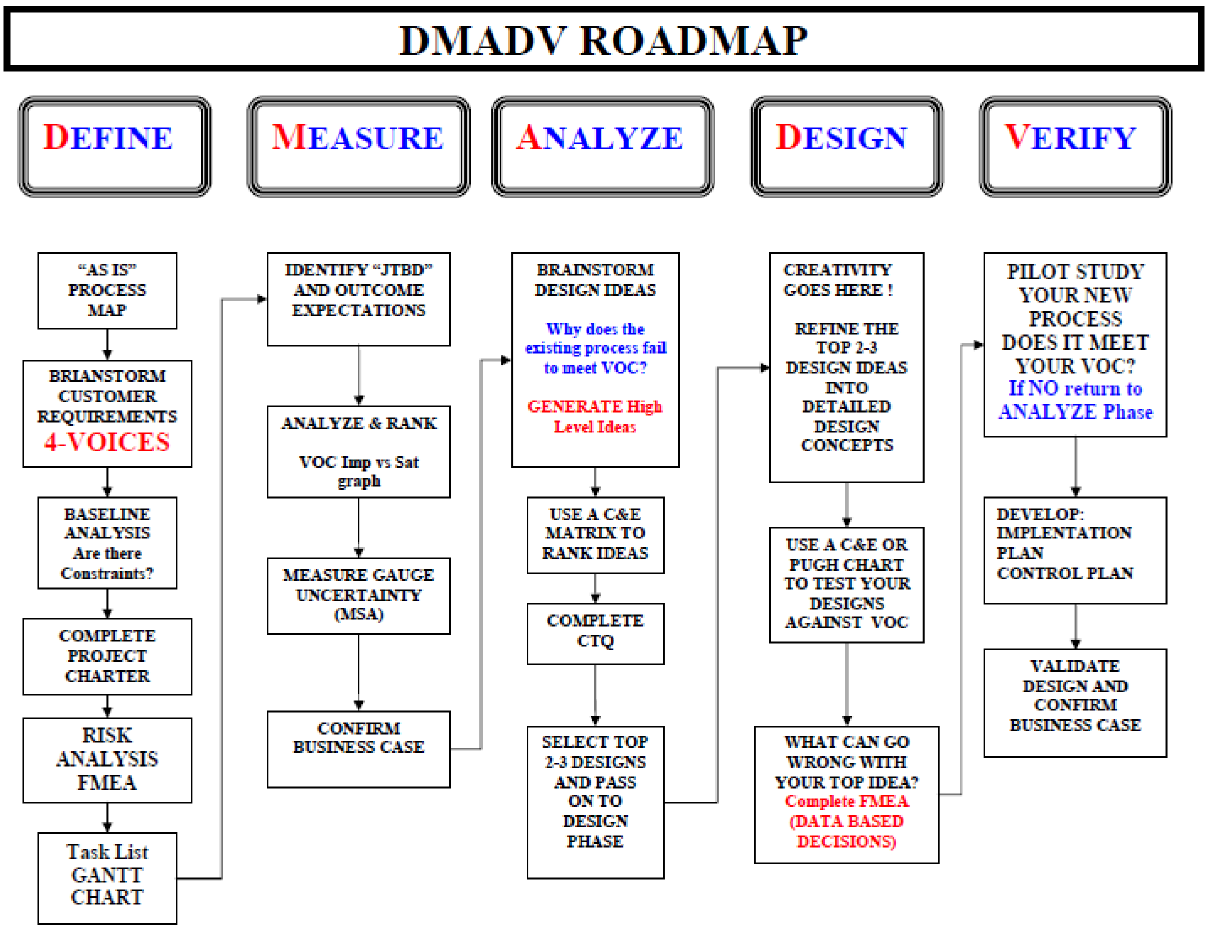

Figure 6: Design for Six-sigma (DFSS)

The advantages of applying this design method to a multidisciplinary project such as this one are as follows:

- Roles and responsibilities within the student design groups are known and accepted by all participants.
- A prescribed method once understood allows for individuals to concentrate on the task at hand. In this case the design of a 3-D printer.
- Following a prescription allows for easier communication between student program groups and across semesters. Everyone is speaking the same language.
- The DFSS method is a standard method used in most sectors of manufacturing. Familiarization of the method will be an asset to student development.

There now follows a detailed description of each phase of the project including student work and outcomes. For each phase a brief description of the order and specific tools used will be discussed.

Define Phase

The function of the define phase is to scope down the project to realistic proportions, determine customer requirements, define baseline data in the form of competition specifications, assess possible project risks, and finally construct a realistic and informed project time line. For any project it is very important to initially define the requirements for the project. As discussed previously the project goal was defined as the manufacture of a desktop 3-D Printer with the capability equal to or exceeding that of the XYZ Da Vinci 1.0 3-D Printer situated in a mechanical engineering technology laboratory.

The initial steps in scoping out a project consist of either defining a high level process map or, as in this project, listing the requirements in constructing and assembling a 3-D Printer. Once listed the inputs, outputs, suppliers and customers can be defined. This completes the Suppliers, Inputs, Process, Outputs and Customers (SPIOC) diagram, Figure 7.

Suppliers	Inputs	PROCESS	Outputs	Customers
McMaster Carr	Tolerances	Prototype Board	Formal Design of Printer Mechanics	Students
Big Bearing Store	Material Choices	Coding Control Loop	Code Outline	Faculty
MiSUMi	Review Preliminary Designs	Wiring Diagram	Printer Board	
Pololu	Size Requirements	Cost Analysis	Wiring Diagram	
Kysan Electronics	Drawings of Parts	3D Analysis	Printing Abilities	
Newegg	Design Software		Functionality	
Arduino	List of Outputs to Printer			
UltiMachine	Motors			
Amazon	Power Supply			

Figure 7: SIPOC diagram of student project

The SIPOC diagram represents the process at a high level and so it is necessary to dive a little deeper and assess customer impact through a tool called the four-voices, Figure 8. The 4-voices represent the voices of the customer, business, process, and employees. Often the impacts listed are used in quantifying differences in process improvement or designs.

VOC Voice of the Customer	*What is important to external and internal customers?* Ease of Use. Any customer using the printer will want it to be fast and simple.
VOB Voice of the Business	*List what is critical to the success of the business?* Currently we are unconcerned about this voice.
VOP Voice of Process	*What output does the process value the most?* *The primary and consequential metrics* Materials used in terms of the type of plastic the printer will use to print parts. The power requirements of the system overall and how it will tax each moving part. Finally the workspace the printer has avaliable to use and operate in.
VOE Voice of Employees	*What concerns do the employees have about this project?* Employees will want the system to be safe, and need a relatively low technical ability to use the printer.

Figure 8: The 4-Voices diagram assessing the project impact on customer requirements

This now completes the define phase. The objective statement can now be written and a time line developed typically based on a Gantt chart, Figure 9.

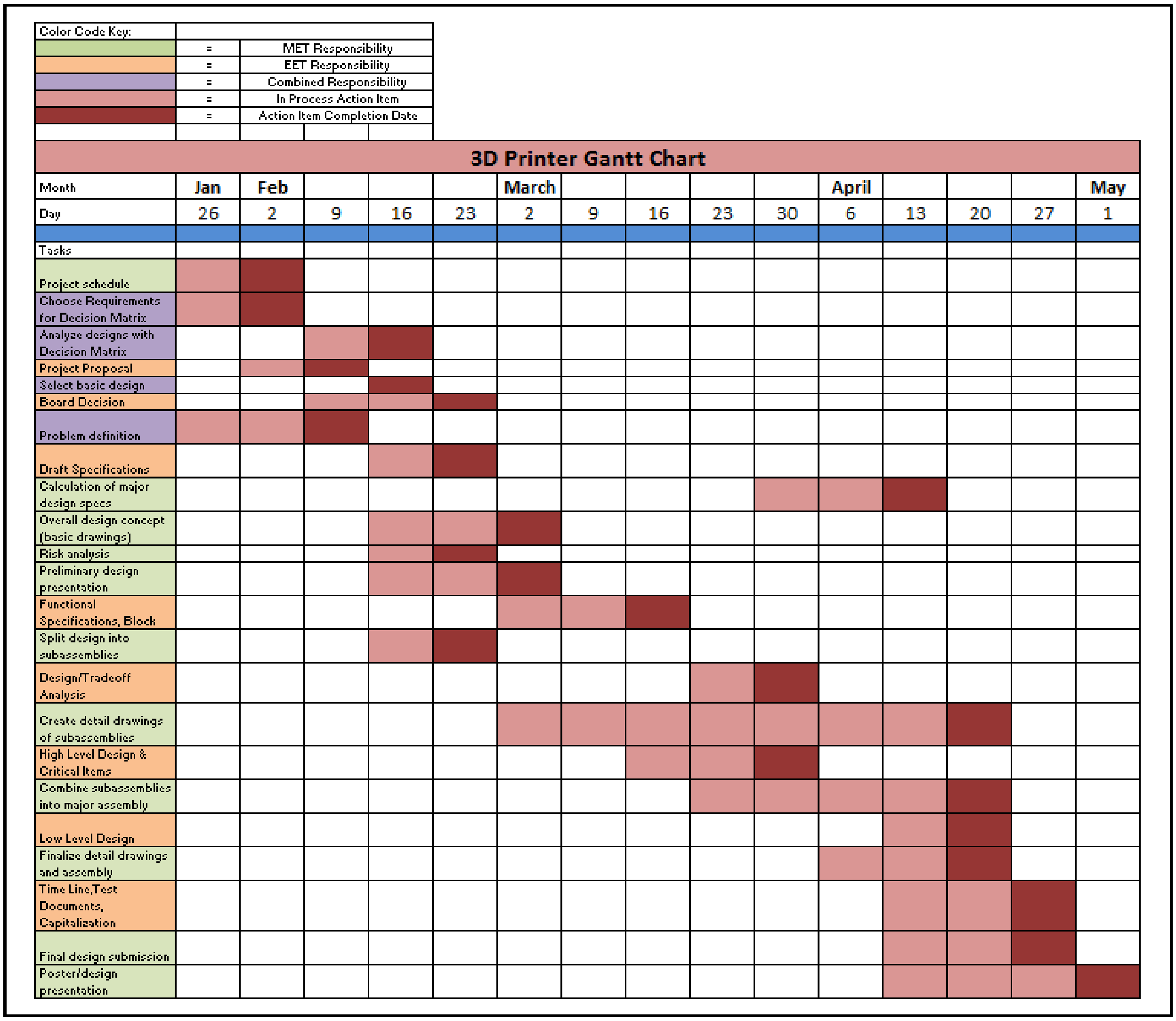

Figure 9: Gantt chart for the initial design of the 3-D printer.

Measure Phase

In the measure phase measurement systems are analyzed to determine if indeed they are adequate for the task of differentiating between individual designs or process improvement strategies. In addition, brain storming events are used to add to add to the list of design factors used to differentiate designs in the Analyze and Design Phases, Figure10. As a result the brainstorming and 4-Voices events the students determined that cost, ease of use, size of print area, Safety, resolution, and overall customer satisfaction are all factors to be used to differentiate between their new designs.

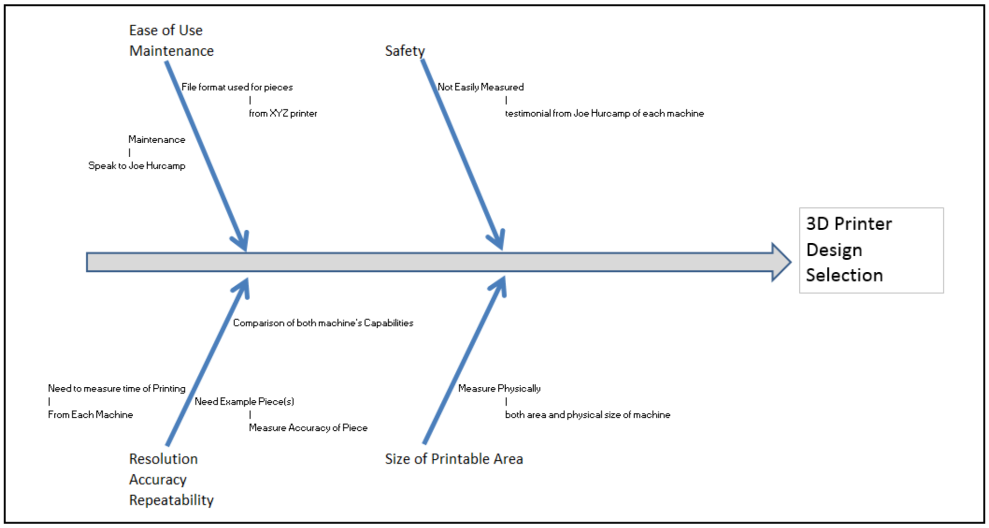

Figure 10: Fishbone diagram containing an overview of the brainstorming event

Analyze and Design Phase

The decision was made to limit the students to six base design that could be enhanced to meet specifications. The first step is to compare each of the six designs to the design criteria (figure 11). The goal of this to funnel the selections to two designs which can be further compared against the DeVinci 1.0 competitive design using a Pugh Matrix (figure 12). The students selected the Wallace design.

Design Criteria / Weighting Factor / Designs	Cost	Ease of Build	Size of Printing Area	Safety	Ease of Use/Maintnence	Resolution, Accuracy, & Repeatability	Overall Satisfaction
	$	Pass/Fail	0.1667	0.2333	0.3	0.3	1.0
Wallace	200-400	Pass	7 / 1.1669	3 / 0.6999	9 / 2.7	10 / 3	7.5668
RepRap Tricolor	800-1000	Fail					0
Prusa Mendel	450-700	Pass	5 / 0.8335	1 / 0.2333	2 / 0.6	4 / 1.2	2.8668
Original Mendel	520	Fail					0
MendelMax	1000	Pass	8 / 1.3336	4 / 0.9332	7 / 2.1	5 / 1.5	5.8668
Huxley	600-700	Pass	4 / 0.6668	3 / 0.6999	9 / 2.7	2 / 0.6	4.6667

Figure 11: Solutions Matrix to select two possible solutions

	Pugh Matrix			
	Base Line		Alternative Solutions	
Criteria	XYZ Da Vinci 1.0	Weight	Mendel Max	Wallace
Cost	$600	-	-1	1
Ease of Build	-	-	1	1
Size of Printing Area	5	5	1	1
Safety	5	7	-1	-1
Ease of use/Maintnence	5	9	1	1
Resolution, Accuracy, &Repeatability	5	9	0	1
Sum of all Positives			15	25
Sum of all Negatives			8	7
Sum of all Neutrals			0	0
Total			7	18

Figure 12: Pugh Matrix to select solution for implementation

From the Student's point of View (by Jacob Smith)

Under the job of being one of the two project managers for the second phase of this project, of designing and implementing a 3-D printer, many skills and tasks were required to complete the overall requirements of the project in a complete and expedient manner. These skills include, for the first phase of the project, understanding of electrical systems to the point of being able to make distinctions in part choice and proper implantation of these electrical components in part of a design along with time management and interpersonal communications. These secondary skills were shown in my personally being the one to set up the times for the EET and MET group meetings in both the first and second phase of the project along with making sure that each member of both groups and both project heads were up to date on all information regarding the project through personal communication or through being the one that wrote the notes from the project meetings each phase had. The skills necessary in the second phase of the design were much of the same responsibilities as the first phase in terms of managerial skills required, but the second phase required implementation of the electrical systems chosen in the first phase. These implementations included proper instillation of heated elements within printed parts and onto the printer frame itself, wiring the entire system in an orderly manner, and properly storing the microcontroller into a separate and secure enclosure with the wire leads from the rest of the system. Much of this work was completed by my partner for the project, and fellow project manager for the second phase of the project, Ross Buttrum.

The tasks required of the EET group overall were reflective of the necessary skills of both phases of the project. In this case it involved going through a selection process to properly choose and implement an electrical system in a 3-D printer that was comparable to a printer currently in the ET building of IUPUI. Secondarily our managerial responsibilities became more stringent in the second phase of the project because there was a new group of MET students inheriting the project, as the MET degree only requires a single semester of a senior project and the EET degree requires two semesters, and both Ross and I had to get the new group up to date on their responsibilities in the project as it currently stood at the end of the first phase.

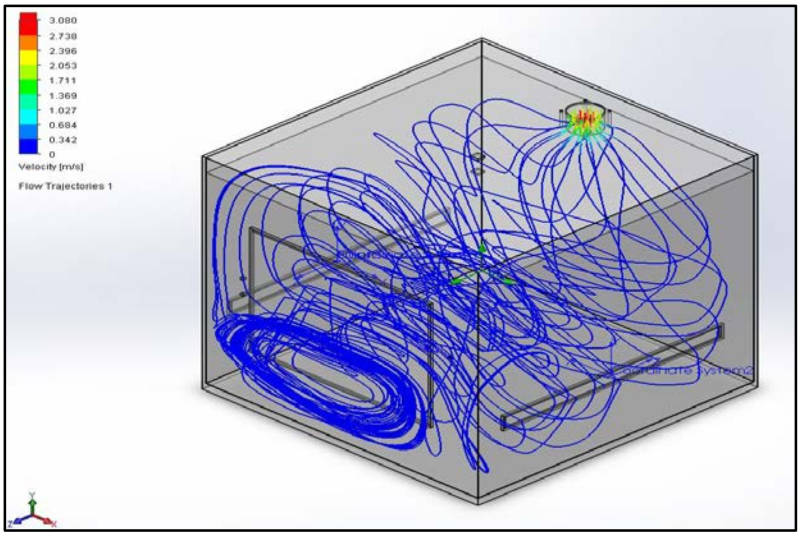

Figure 13: CFD investigation of air flow in preliminary enclosure design

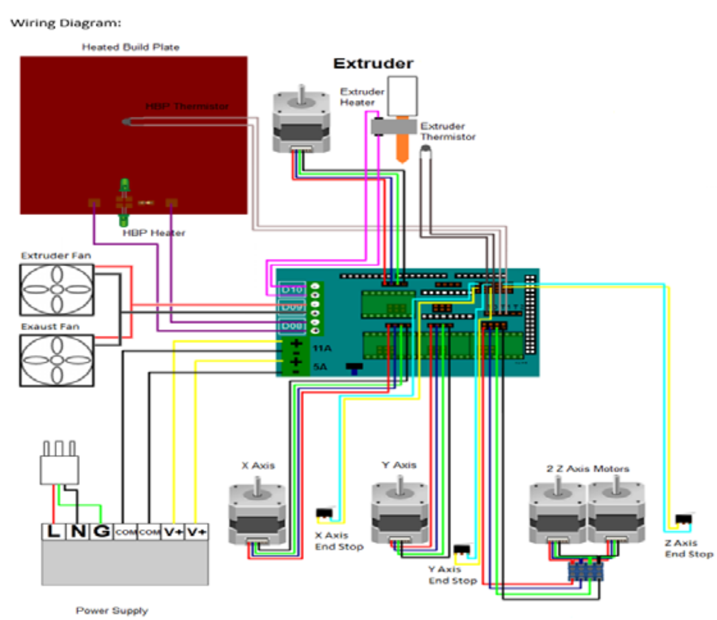

Figure 14: Electrical diagram of control system

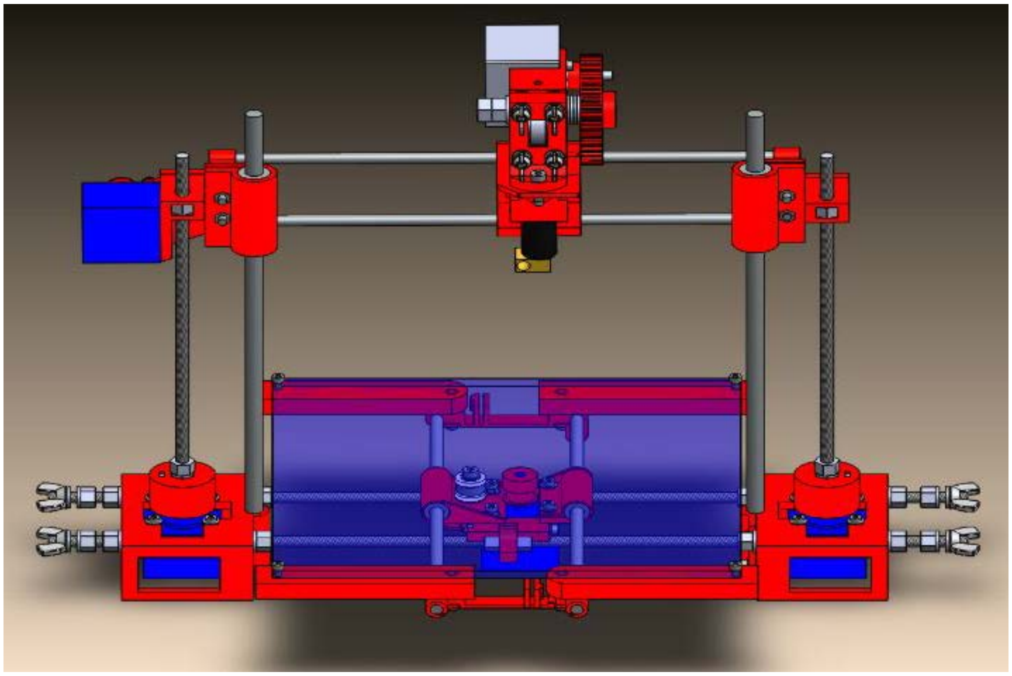

Figure 15: Preliminary mechanical design setup based on modification of Wallace design

To describe both phases of the projects fully would take a separate paper in itself, and if you are curious to read such a paper it can be found in the records of IUPUI as senior project reports are kept for future students to look at. However a brief summary of each phase will be provided here including the basic procedures and methodologies of these actions within the phases. The first phase of the project was by far the heaviest. In its onset we, Ross and I, were contacted by our project lead Prof. Elaine Cooney to participate in the interdepartmental project of building a 3-D printer with a group of MET students, which we later realized would be two groups of MET students. First and foremost we had to find a room to hold meetings in which after it was suggested we use a conference room for such meetings it was agreed that that would be the best approach. When we finally all got together in a meeting we began on the project in earnest. After initial introductions we began under Prof. Yearling's suggestion to go through a basic design process that began first with brainstorming what would need to go into the printer in the first place. After this we separated out these ideas into groups that covered specific areas, and we sent out surveys to gauge the importance of these particular areas. With these survey's returned we had a good basis for looking at a series of printers, of Prof. Yearling's choice, and choosing between these printers to see what design we would implement. We narrowed down six choices to two through presentations and voting, and the further two were separated with the help of a Pugh Matrix. When this final choice was made we separated out exactly what responsibilities we would have for the design phase, basically boiling down to the METs would handle the housing of the printer's electrical components, the motors that would control the axis that held the heated print head, and getting together the 3-D printed parts that we could create at the school, and the EET group would handle getting the electrical systems working which included the microcontroller, the computer system that would take model files to print and convert them to printable instructions, and the heating elements of the printer. All throughout this design phase each group had multiple series of assignments that needed to be completed for their senior project class, along with the design meetings themselves Phase one culminated after many meetings maintained initially by myself acting in a managerial role as described earlier in the complete design of the printer having been made by the first group of MET students.

Phase two started out similarly; first we were introduced to a new group and from there we went through a quick summary of the design work that had already been completed on the project so far. To these ends I set up a new meeting time, once weekly where and when the group could meet, and the project leads took this chance to back off on the help they had given so far in Phase one trusting the work that Ross and I had put into the project to keep the new group up to date and move the project forward. We in turn kept the leads fully up to date on any developments or problems the project seemed to be facing, and these problems started amounting quickly. First came the issue with the designs from Phase one; the issue being that the first group of METs had apparently done a very poor job with the design and the new group had to redesign nearly every aspect of the printer to fit the design requirements. These designs included correcting multiple issues with the base holding a heated print bed, fixing the axis that would move the hot end of the printer in a housing, multiple issues with the transfer mechanism that moved material through that hot end, and issues with the design of the housing of the heated end overall. Conversely the EET side of the project had very few problems with implementation of their systems, the largest problem came from the breaking of an important thermistor that was replace and repaired, other minor issues came in dealing with a bowing in the heated print bed due to material used to hold the heated print bed in place. Throughout this proper communication was maintained, and calm when issues arose helped us carry through because of this communication. Proper documentation and interdepartmental dealing led the project to being successfully concluded with one of the very few, if not only, interdepartmental projects to have been successfully completed for a senior design phases.

Conclusion

Both the faculty and the students observed that the semester one design phase was easier than the semester two build phase. Second semester students complained during the build phase that initial design did not meet build specifications, it was impossible to build, it didn't allow for control cabling, etc. It isn't until a design is constructed and tested that problems are identified in meeting the customer specifications.

The MET curriculum structure required two distinct teams (one for design and one for build) who didn't communicate well. This created some problems with the design (as described above) but was mitigated through the project methodology. By instructional design, there were technical communication issues between disciplines at beginning of semesters. The root issue was the students' lack of experience identifying roles and responsibilities and running a meeting. As anticipated, the use of standardized meeting agendas mitigated this problem. As a result, students gained confidence and were able to focus on the technical issues at hand.

The MET students benefitted from interacting with EET students to appreciate the importance of control systems, and the EET students learned the importance of thermal design of enclosures. As graduates, these students will be open to working with other disciplines and flexible in their communication strategies.

In the future, more multidisciplinary projects are planned – some with local industry and some for the university. The syllabi will be synchronized for the MET and EET project courses to facilitate joint projects.

For the faculty, this was very successful project, because the students demonstrated the following outcomes:

- Define and solve a broadly defined technology problem
- Design a system requiring expertise from many disciplines.
- Function on multidisciplinary teams

Upon graduation, these skills can be easily transferred to the workplace. Finally, there is a new 3-D printer in the school's lab for student (and faculty) use.

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