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A Hands-On Manufacturing Curriculum for High School Students

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A Hands-On Manufacturing Curriculum for High School Students

by

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Thesis

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Dedication

As a child hailing from India above all I learnt above almighty there are three more important things. They are MATHA, PITHA, GURU & DEIVAM. I would like to dedicate this to them in the same order age old saints few thousand years back have penned down in the Upanishad (Old textbooks on way of life). MOM, DAD, TEACHERS and finally GOD!

Acknowledgements

My internship with Dr. Beaman during my undergraduate degree and his recommendation letter are two of the reasons for my admission to The University of Texas at Austin. I am always grateful to him for that. Dr. Richard Crawford has been a turning point in my career. I have never been interested in pure equations or fascinated by pure academic content where the real life application is not seen. As first-year students in graduate school most of us tried to pursue research projects with funding. I too got caught in that trap and initially took up a research project under a renowned professor on a highly mathematics and equation oriented project. Although I did not like the project, the alluring funding in that project made me accept it. Sometimes the course of life is shaped by the circumstances and when we are about to crash, fortunately we enter into the Auto Pilot mode! Dr. Crawford's research was one such blessing. When I learned from another student that his research was developing hands-on curricula for high school students, I was attracted by it. I immediately met him and suggested my own research topic to him. Although the project did not have funding, I worked under the same professor as a Teaching Assistant and did what I love without compromising on the funds. I learned a lot from Dr. Crawford and saw my transition from a child to an adult. He gave me complete independence, and when I got feedback towards the end on the success of the curriculum as tested at Bowie High School, I guess that made all my hard work worth it. I would next like to thank my brother who played the role of my dad and taught me relentlessly without losing patience whenever I did not understood some lessons or concepts. I would also like to mention Sathan, my friend, who motivated me, believed in me and made me realize my potential. Special thanks to my dear friend Mansi who played a pivotal part in motivating me and encouraging till the very end. Finally I would like to thank my mom, without whom none of the above would have been possible. She has been my backbone, pillar, support and strength in my entire life.

Abstract

A Hands-On Manufacturing Curriculum for High School Students

by

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The University of Texas at Austin, 2015

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The UTeach*Engineering* program in the Cockrell School of Engineering of The University of Texas at Austin has developed a high school engineering curriculum, *Engineer Your World (EYW)*, with the intent of interesting students in pursuing Science, Technology, Engineering, and Mathematics (STEM) careers. However, *EYW* currently contains no curriculum modules on manufacturing. In fact, a literature review shows very few high school manufacturing curricula, and these typically require state-of-the-art manufacturing facilities, thus making the curricula unaffordable to many schools. Thus, there is a need to develop a new manufacturing curriculum module to provide all schools with the opportunity to teach the breadth of the core concepts of manufacturing without being limited by constraints, such as finance, materials, facilities, etc. This thesis presents the details of such a module. The hands-on approach for teaching manufacturing bridges the gap between theory and practice. Students first learn manufacturing techniques in detail, and then manufacture a simple product using simple setups designed to provide concrete experience with a particular manufacturing process. The hypothesis is that, after completing the module, students' understanding of manufacturing is increased compared to that before the module. This thesis describes the curriculum and its evaluation. The capstone module of the curriculum features an inexpensive surrogate manufacturing machine that can be assembled quickly by teachers or students to provide hands-on experience. The capstone module of the curriculum was tested with students from an engineering class in a high school in Austin, TX, USA. A pre-test/post test was conducted to evaluate the effectiveness of the curriculum. It was found that the curriculum was simple to understand and implement and also provided insights into manufacturing which are similar to what could be attained with a module using more expensive manufacturing equipment.

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CHAPTER 1: Introduction

There has been considerable interest in Science, Technology, Engineering, and Mathematics (STEM)[1] education in the past few years. According to Forbes, "Only 5% of U.S workers are employed in fields related to science and engineering, yet they are responsible for more than 50% of our sustained economic expansion"[2]. With advances in science and technology, the need for more specialized employees is on the rise. It is here that the need for engineering graduates is imperative. Schools have taken initiatives to expose students at an early level to STEM education. As part of these initiatives, engineering curricula have been developed which give students a broad introduction to topics. The *Engineer Your World* (*EYW*) curriculum, developed by the UTeach*Engineering* program at The University of Texas at Austin focuses on engineering design. However, *EYW* contains no curriculum modules on manufacturing. As a mechanical engineer fascinated with manufacturing I was curious to develop a short module for manufacturing to be added to the *EYW* curriculum. This served as the starting point for the research reported in this thesis. In fact, a literature review showed very few high school manufacturing curricula, and these typically require state-of-the-art manufacturing facilities, thus making the curricula unaffordable to many schools. This validated the need to develop a new manufacturing curriculum module to provide all schools with the opportunity to teach the breadth of the core concepts of manufacturing without financial, material, or facilities constraints.

1.1 UTeach*Engineering*

UTeach*Engineering* is a project at The University of Texas at Austin funded by the National Science Foundation's Math and Science Partnership program. It has been an innovator in the field of high school education since 2008. *Engineer your World* is one aspect UTeach*Engineering*.[3] *EYW* is an innovative student-centered curriculum that facilitates student engagement in authentic engineering scenarios and inspires the students to think like engineers.[3] The goal of the curriculum is to combine concepts across various disciplines to deliver content that is relevant and as close to the real life challenges the student could face. The goal of *EYW* is to not turn all students into future engineers but to inspire the students to adopt an engineering approach in solving real world problems in any discipline.[4] The curriculum covers a breadth of different engineering topics, such as engineering design, reverse engineering, systems engineering, programming micro-controllers, etc.[5]

Manufacturing is not covered in this curriculum, providing an opportunity for research to enhance the existing *EYW* curriculum. The literature review in the next chapter justifies the need for such a module. As part of the background research I visited two high schools in Austin, TX, USA, to gain insights on how engineering is taught at the high school level and to gage the interest in manufacturing. This is discussed in the next section.

1.2 Engineering in High Schools in Austin

The schools visited were Anderson High School and Bowie High School, both public schools in the Austin Independent School District (Austin ISD). At the time of writing this thesis, Mr. John Sperry teaches Manufacturing to students at Anderson High School. On visiting his class on manufacturing, I learned that some schools indeed teach manufacturing. The problem is not whether it is taught, but how it is taught. Manufacturing by its nature involves fabricating physical objects. I understood from Mr. Sperry that having students actually use basic manufacturing equipment, such as a milling machine and lathe, is imperative. Substitutes, such as videos, are not as effective as manufacturing an actual part. Mr. Sperry's opinion is consistent with the literature, and explains why very few high school curricula on manufacturing exist. Very few schools have access to a complete manufacturing laboratory, such as the one at Anderson, which is equipped with a lathe, a milling machine and even a state-of-the-art 3D printer. This barrier to accessibility of manufacturing to all schools results from the very high initial equipment investment. The course taught at Anderson High School is a one year long in-depth course on manufacturing based on the Texas Essential Knowledge and Skills (TEKS) standards as dictated by the Texas Education Agency (TEA).[36]

The second school visited was Bowie High School, where Mr. Mike Evans teaches an introduction to engineering course. On observing that class I understood that project-based learning was essential for the success of any engineering curriculum. The students in that class were working in teams of four to build rockets, which was a project based on one of the previous lessons in that course. Mr. Evans explained that this hands-on approach gives students a platform to put the academic skills they have learned into practice, thereby bridging the gap between theory and practice. Additionally, observing their science fair gave critical information on quantifying and qualifying the prototyping abilities of high school students. Interacting with the students gave deeper insight into their understanding and the way they present their thoughts. This accentuated the need to develop a manufacturing curriculum centered on project-based learning. Unlike Anderson High School, Bowie does not have state-of-the-art facilities or a well-equipped laboratory for manufacturing. Mr. Evans agreed to pilot a section of the curriculum developed in this research, since our curriculum targets schools which are constrained financially from obtaining a lathe or milling machine.

1.3 Significance of Manufacturing

Everything around us is manufactured. From safety pins to spacecraft, modern products must be carefully fabricated. Hence it is imperative not only to understand how things are made, but also to appreciate the beauty in things that have been crafted in one way or another.

Merriam-Webster defines manufacturing as “something made from raw materials by hand or by machinery”.[6] Since manufacturing, engineering and design go hand in hand[7], it is only fair that curricula that teach engineering design, such as the *EYW*, focus on manufacturing as well. According to Deiter and Schmidt, “Manufacturing has been downplayed in the education of engineers. Manufacturing positions in industry have been considered routine and not challenging and as a result they have not attracted their share of the most talented engineering graduates.”[7] This trend has to change. One of the issues industry has been facing is the separation of design and manufacturing.[7] This leads to barriers which inhibit the close interaction of these two aspects of engineering. This observation is evident even in high school curricula. The *EYW* curriculum, for instance, focuses only on engineering design and not manufacturing. Thus, since technology is sophisticated and fast changing, collaboration between research, design and manufacturing is required in order to push boundaries.[7] These reasons indicate the need for a curriculum focused on manufacturing.

1.4 Requirements of the Module

There are numerous concepts which might be included in a manufacturing module. Adequate presentation of these concepts at the high school level requires varying time spans and depth of coverage. We must ensure that the concepts taught provide adequate depth to equip the student with the essential information needed for understanding manufacturing processes. In particular, the concepts should serve as tools to assess the capstone project included in the module and provide depth of understanding of the various manufacturing processes.

There are several ways of teaching these concepts. A key is to connect these concepts directly to real manufacturing processes. High school students are really inquisitive as compared with the college students.[8] According to Mr. Evans' observation, students become very engrossed in a topic if they find it engaging. However, they may lose interest right away if they think the topic is not intriguing enough. Hence, it is imperative to support the teaching of a concept with concrete rationale and justification of its relationship to manufacturing. The value of the concept to the students should be clear. Once the students are able to connect the dots and see the real life application of the concept, it will improve their engagement.[8]

1.4.1 Duration of the Curriculum Module

The question then arose as to the length of the curriculum module designed to be plugged into the existing engineering curriculum. More details on the requirements and constraints are discussed in Chapter 4. Mr. Evans provided enlightenment on the role that teachers play in adopting any new curriculum module. Since teachers serve as gatekeepers to the curriculum, any new module should not be too time intensive as the teachers may find it hard to fit it into their existing curriculum. Thus, he suggested that the curriculum module be designed for three weeks. However, modules in *EYW* are generally longer to allow schools to teach the concepts in some depth. So it was decided that the length of the manufacturing module should not exceed six weeks. This timespan gives schools some flexibility in length and depth of coverage of the subject. The module is structured with basic concepts and more advanced topics. If the module must be taught at a quicker pace, then the basic curriculum can be taught to cover the concepts in three weeks. Alternatively, schools can choose to delve a little further into the subject by teaching the full six week module.

1.4.2 Cost of the Curriculum

Based on the literature review and benchmarking at Austin ISD high schools, it is clear that cost is indeed a barrier for integrating a manufacturing curriculum at the high school level. Even low cost curricula such as *EYW* require an annual license fee and have upfront costs for permanent equipment.[5] Since Bowie High School was our target customer, and as they do not have manufacturing facilities, Bowie provided an excellent benchmark for the cost of the module. Mr. Evans suggested that $20 per student for six weeks is a fair cost. With about 20 students in the class, the total target cost is $400. Compared to other available curricula, this is a relatively low cost curriculum.

1.5 Curriculum Development Process

A systematic approach is needed to develop a successful curriculum[9]. According to Stabback et al.[9], four broad areas must be addressed:

1. Focus on learning and learners in the curriculum
2. Content and delivery of the curriculum
3. Documentation of the curriculum
4. Curriculum development processes, including monitoring and evaluation.

Point 1 can be covered by emulating the tried and tested learning strategies as discussed further in the literature review chapter. The initial interactions with students at the science fair, in their classes and observing their projects further assisted in this process. The second point calls for a special framework called the “Understanding by Design” approach which focuses on the end goal first and working backwards.[50] This is discussed further in Chapters 2 and 4. As for the documentation of the curriculum, Mr. Evans suggested that most of curriculum modules are hard to implement as they end up being too verbose and difficult to understand. Instead, he suggested videos and presentations are more effective and usable forms of documentation of the curriculum. This approach was validated when a sample section of the module was taught by Mr. Evans to his students using the presentation slides developed as part of this research (see Appendix B) and a demonstration of the capstone project was conducted. The outline of the curriculum so developed and its Performance Tasks are documented in Chapter 4. The final point in the curriculum development process discusses monitoring and evaluation. As discussed above, a section of the curriculum was evaluated using pre-tests and post-tests. The results of this evaluation are discussed in Chapter 6 and general conclusions drawn from the research are discussed in Chapter 7.

CHAPTER 2: Literature Review

This chapter reviews the existing literature on teaching manufacturing at the high school level. The purposes of this review are to identify the current shortcomings in any existing curricula and to give a broader understanding of the goals of preparing such a curriculum. The review uncovered a lack of broad curricula on manufacturing that meet the constraints discussed in Chapter 1.

Thus, the literature review gives deeper insight into the overall picture and challenges of teaching engineering in high school. This background lays a strong foundation for identifying the different methodologies adopted for teaching manufacturing and understanding the extent to which manufacturing has been covered at the high school level. The literature review focuses on the following areas.

1. Engineering in high school.
2. Manufacturing education in high schools.
3. Key concepts for learning manufacturing.

2.1 Pre-College Engineering Education

2.1.1 Existing Curricula and Their Problems.

There are several commercially available engineering curricula, such as Project Lead the Way (Indianapolis, IN, USA, https://www.pltw.org/), the Infinity Project (Dallas, TX, USA, http://www.smu.edu/Lyle/Institutes/CaruthInstitute/K-12Programs/InfinityProject), and digital libraries funded by NSF and ASEE, such as TeachEngineering (https://www.teachengineering.org/), Community for Advancing Discovery Research in Education (CADRE, cadrek12.org), and eGFI (http://www.egfi-k12.org/). The research team for the Innovation Curriculum for Engineering in High School (ICE-HS) was developed to address the need of defining an engineering curriculum in a charter high school. As a part of their research, the team reviewed several vendor prescribed curricula, such as those mentioned above. According to ICE-HS, "the inflexibility of vendor sold curricula and lack of structure with the digital libraries posed some challenges for teaching engineering in high school."[33] This finding was supported by their study at Davinci School for Science and the Arts (El Paso, TX, USA), which found the vendor specific engineering curricula expensive to implement. More details on this study are discussed later in this chapter. Although the teachers in the school received training from the vendors of these curricula, they lacked the structure to introduce a discreet engineering course in high schools which catered to all the students. ICE-HS hence concluded that the school needed to customize available curricula for implementing a discrete engineering course in high schools.[33] ICE-HS was asked to address this need.

2.1.2 Benefits of Engineering to High School Students

The idea that engineering increases creativity in students was supported as early as 1976 based on a five week summer program offered at the Christian Brothers University.[10] Engineering provides the skills needed to solve any problem or meet any challenge.[9] Engineering also helps students make connections to understand the complementary relationships between science, technology, engineering and mathematics.[9] Most importantly the spatial skills of students can be significantly increased when exposed to engineering at the high school level.[12] Spatial intelligence is the ability to visualize the shapes and geometry in one's mind. In a study conducted by Brudigam and Crawford, 207 high school students in a geometry class, some of whom were also enrolled in an introductory engineering course, were administered a standard test of spatial reasoning. The study found significantly higher test scores for those students enrolled in the engineering course.[12] Research suggests that spatial thinking is an important prerequisite of achievement in STEM coursework and careers.[9] Numerous experiments report that after a short training period (ranging from hours to a few weeks), students of both sexes improve their spatial skills.[13] Spatial training also improves children's mathematics abilities.[14] Based on these studies, it is reasonable to assume that engineering activities can increase the spatial intelligence in high school students as well.

2.1.3 Need for High School Engineering Curricula

According to the U.S. Bureau of Labor, the estimated number of jobs to be filled in engineering and science will grow at more than three times the rate of other professions. According to the U.S. Department of Commerce, by the year 2018, jobs in STEM fields will have grown by 17 percent.[15] This is expected to almost double the growth rates for non-STEM majors. [15] Additionally, the U.S. Department of Commerce predicts that there will be about 1.2 million vacant STEM positions in the United States by the year 2018. [15] These predictions suggest that STEM is where jobs are today and where job growth potentially will be in the future. To cater to this need and motivate budding engineers to take up engineering as a career path, early introduction to engineering at high schools would be useful.

It is also interesting to note that 40 to 50 percent of college engineering students switch to other majors or drop out of college after enrolling in an engineering school.[16]. A recent study of 113 undergraduates from large top tier institutions in the eastern United States, who left engineering in 2004, 2007, and 2008, pointed to three key reasons: poor teaching and advising; the difficulty of the engineering curriculum; and a lack of a sense of belonging within engineering.[17] These factors affect a student's self-confidence in his or her ability to perform.[15, 16] This accentuates the need for introduction of high school engineering programs and curricula to bridge that gap. Colleges may have state-of-the-art laboratories and professors may be experts in solving complex problems. But a freshman in college is not far removed from a high school student in terms of engineering intellect. The demands of a college engineering curriculum can be overwhelming to the point that a student is left with no option but to quit. High school engineering courses provide one way to bridge the gap between the education in high schools and colleges.

2.1.4 Other Initiatives to Expose High School Students to Engineering

Several organizations have already taken the initiative in this regard. One of the early ones to take initiative in this space was mentioned above: the Christian Brothers University.[10] Their Early Identification Program seeks to introduce high school students to engineering. It is a five week summer program that has evolved over the years. The students were given a capstone project of building a scaled-down version of an actual tower. In addition, the students attended seminars by eminent engineers and were taken on field trips. Many such enrichment programs are offered by various universities, including summer camps. Many, however, are paid programs or rigorously screen applicants so that only a select few are admitted. The University of Alabama charges $1850, for one such program.[19] My Introduction to Engineering is another program organized by The University of Texas at Austin for students with strong interests in engineering, science or mathematics.[20] The program especially targets populations who are underrepresented in engineering. Other noteworthy colleges to offer such initiatives include MIT and Stanford. These camps are generally organized during the summer and have limited admission. Many are also expensive to attend.

2.1.5 Insights from Existing High School Engineering Curricula

To reap the benefits of high school engineering and address the issues cited above, a strong curriculum should be introduced. There are several vendor prescribed curricula, and some universities offer curricula tailored to the needs and interests of high school students. Project Lead The Way (PLTW) claims that they are the nation's leading provider of K-12 STEM programs. [21] Additionally, PLTW claims that their "…world-class curriculum and high-quality teacher professional development model, combined with an engaged network of educators, help students develop knowledge and skills essential to succeed in the global economy"[21]. One of the most important insights gained from studying this program is the role of active learning. Traditionally students are passive recipients of information in a question-and-answer, right-or-wrong learning environment[22]. The unique selling point of PLTW is project-based learning. Historically, mathematics and science have always been taught in isolation.[23] PLTW changes this conventional approach by encouraging students to learn by applying mathematics and science principles in design activities geared towards unique solutions and problems. They also help students realize the relevance of engineering to the enhancement of their lives and future careers. PLTW also adopts Wiggins and McTighe's "Understanding by Design" approach to develop a more unified and lucid instructional path for students.[15] They also adopt a problem-based approach for student learning by providing rigor and relevance that paves the way for increased student engagement.[15]

As described in Chapter 1, *Engineer Your World* is a product of the UTeach*Engineering* project at The University of Texas at Austin.[3] *EYW* is designed to empower students to think like engineers in the context of collaborative, student-directed projects that develop strong problem-solving skills.

TeachEngineering is a searchable digital library collection available online. It has engineering curricula that cater to K-12 students, teachers and engineering faculty. It adopts an engineering design approach for making applied science and mathematics more engaging.[26] The TeachEngineering collection provides educators with complimentary access to a growing curricular resource of activities, lessons, units and laboratories. Research on effective learning in K-12 classrooms demonstrates that an engineering approach to identifying and solving problems is valuable across all disciplines[26]. TeachEngineering uses the engineering design process and team work as their central theme for teaching. The engineering design process is a series of steps that engineering teams use in order to guide them as they solve problems. The design process is cyclical, meaning that engineers repeat the steps as many times as needed, making improvements along the way. The TeachEngineering curriculum materials are built around encouraging students to follow the steps of the design process in order to strengthen their understanding of open-ended design and emphasize creativity and practicality. The steps involved in this process are shown in Figure 1 below.[27]

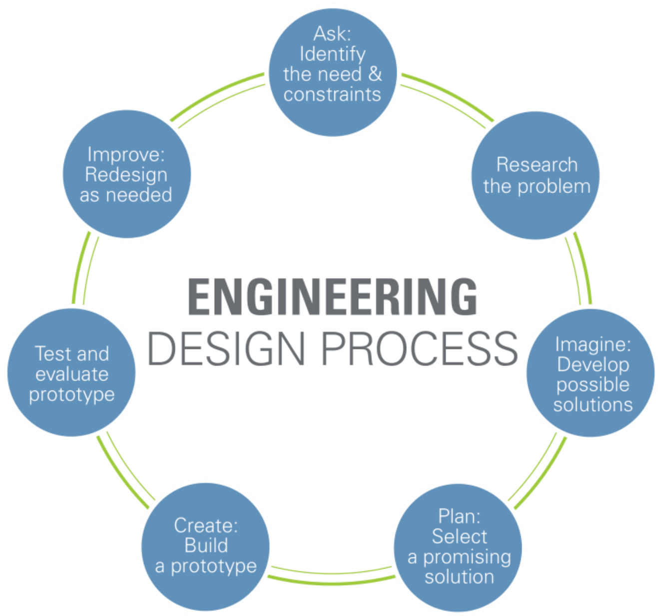

Figure 1. Steps involved in the engineering design process.[27]

Cadrek12.org is another web database for providing engineering curricula. CADRE stands for Community for Advancing Discovery Research in Education. It is the network that provides resources for the National Science Foundation's (NSF) Discovery and Research K-12 program. The NSF's Research on Education and Learning (REAL) program emphasizes building concrete evidence for explanation of the concepts and use of technology to aid the challenges faced in STEM education.[28] This suggests that, by incorporating real life manufacturing examples, our curriculum can be made more effective.

Another key insight was obtained from the Davinci School case study introduced in section 2.1.1. The Davinci School for Science and the Arts is a designated STEM academy funded by the Texas Education Agency's T-STEM Initiative.[29] The school required help to develop an engineering curriculum and teaching methodology that could be offered to all students in the high school by teaching them problem solving and design thinking skills present in all engineering fields.[29] This is different in the fact that the course was offered to all students of the high school as opposed to the traditional method of students' electing a course of their own choice. The course had to be offered for at least three hours a week. As part of the research, the school reviewed the existing engineering curricula sold by vendors and found it cost prohibitive to implement with their budget. It is interesting to note that although, the teachers were exposed to the "tried and tested" approaches like LEGO® Robotics and similar activities, they were unable to introduce a discrete engineering course that catered to all students in their school.[29] It was then concluded that along with an "Understanding by Design" approach, a "systems approach" was imperative for the successful implementation of engineering in high schools.

2.2 Manufacturing Education in High Schools

It is evident that all the engineering programs reviewed so far provide a broad view of engineering, particularly engineering design, but focus little on manufacturing. This section critically analyzes available manufacturing curricula. The depth and breadth to which manufacturing is taught, and how educators address financial constraints, student engagement and lack specialized manufacturing equipment, are discussed.

Many schools like Wheeling High School (Wheeling, Illinois, USA) have developed specific career pathway curricula for students. These typically include yearlong intensive courses that focus only on manufacturing and are geared towards students who already have decided to pursue advanced manufacturing as their future career. Their model, which they claim is based on the Nebraska Career Education model, is shown below.[30] Career pathways are grouped into six fields. These six fields are subdivided into groups of careers that require similar skills, known as Career Clusters. Other states have started similar initiatives.

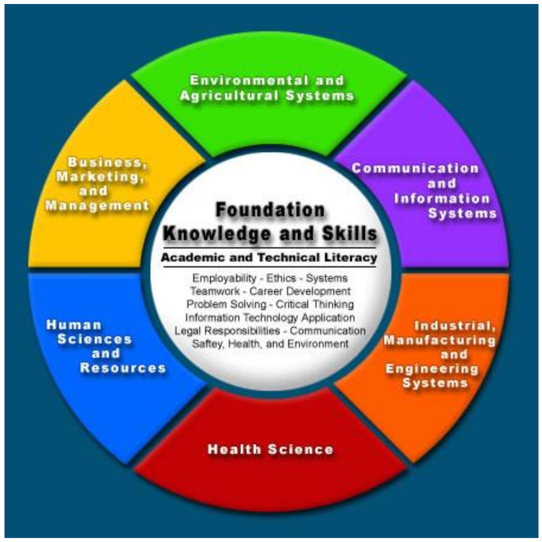

Figure 2: Pie chart showing Career Clusters.[30]

Another example of a career cluster is offered by the State of Washington. Career and Technical Education – Washington (CTE) states that it "promotes and supports locally-based middle and high school programs that provide academic and technical skills for all students".[31] Students that opt for this manufacturing career cluster learn and practice skills that prepare them for post high school education in two to four year specialized college programs. The program also encourages them to pursue training such as apprenticeships. The Washington CTE identifies eight distinct career pathways: production, manufacturing production process development, maintenance, installation and repair, quality assurance, logistics and inventory control, health, safety and environmental assurance.[31]

2.2.1 Need for Manufacturing in High Schools:

According to the Georgetown University Center on Education and the Workforce, by 2018, 42 percent of jobs in manufacturing will require some postsecondary education or a degree.[32] A 2012 Manpower Group study indicated that machine operators and engineers are among the top 10 jobs that U.S. employers have trouble filling.[33] In order to address the needs as stated above, students need exposure to manufacturing in high school to encourage them to pursue manufacturing as a career option. Some schools have invested in equipment for advanced manufacturing, such as 3-D printers, drill presses, milling machines, lathes, laser and vinyl cutters. As discussed previously, curricula based on such state-of-the-art equipment are financially prohibitive for many high schools. Examples of schools which have such state-of-the-art dedicated manufacturing facilities include Sherwood High School in Sherwood OR, and the previously mentioned Anderson High School in Austin, TX.

Other manufacturing curricula reviewed either delve too deep into the subject or merely give an introduction without hands-on experience. One interesting curriculum is an introduction to manufacturing course offered by the Mid-South Community College (West Memphis, Arkansas).[34] The course supplements direct teaching with some hands-on activities. However, it too requires specialized equipment. Furthermore, it did not provide an overview of the different processes used in manufacturing. Other manufacturing courses offered by them such as Production Processes, Power and Equipment Systems, and Manufacturing Enterprise were advanced and detailed, time consuming, and provided depth, not breadth.

The course offered at Anderson High School in Austin, TX is aligned with the Texas Essential Knowledge and Skills (TEKS) for a manufacturing course. The TEKS, maintained by the Texas Education Agency, outline the curriculum content and outcomes for every approved course in the state of Texas.[35] Of the TEKS listed, those which provide the closest match for our target area are the courses “Principles of Manufacturing” and “Manufacturing Engineering”. Most of the other TEKS listed are for advanced and highly specialized topics, such as welding, precision metal manufacturing, and flexible manufacturing. The Principles of Manufacturing course is an introductory course offered for one half to one credit. It provides a strong foundation in the essential concepts such as manufacturing systems, precision measuring instruments, quality controls, manufacturing standards, and safety. However the concepts taught in this course are more academic and theoretical and do not give exposure to the manufacturing processes as such. The tools used for this course are laboratory test equipment. It does not delve deeply into manufacturing processes or provide any hands-on activities to supplement the students’ understanding of manufacturing.

On the other hand, the TEKS for Manufacturing Engineering do provide an elaborate level of detail on manufacturing processes[36.] . However, this course appears to be more intensive in terms of time and effort, and highly specialized. From the TEKS, it was evident that students are expected to gain advanced skills in working with programmable logic controls and use of computer-integrated manufacturing techniques to simulate manufacturing processes. Other topics in the course include design and production on computer numerical controlled lathes and milling machines.

From this review of the literature it appears there is an opportunity to develop a manufacturing curriculum covering the different processes at the high school level. The courses that do justice to the subject are time intensive, or require expensive laboratory equipment. On the other hand, the curricula which give breadth are too superficial and lack emphasis on project-based learning. To address these challenges, and based on feedback from current high school engineering teachers, there is a need to develop a new six-week module on manufacturing which could be plugged into an engineering course. The course will provide an optional three-week module to schools which do not have a dedicated engineering course.

2.3 Key Concepts for Learning Manufacturing

To develop the six-week module on manufacturing, we intended to identify the essential concepts required for learning manufacturing. Existing curricula and the TEKS provided a starting point. There are also various comprehensive textbooks on manufacturing, such as De Garmo et al.[18] and Grover.[24] These resources provide a strong foundation for developing the six-week curriculum module.

Sparks et al. provide key insights based on the concepts they focused on in a workshop conducted for high school teachers and students on advanced manufacturing at the University of Missouri-Rolla.[37] The purpose of the workshop was to expose teachers to manufacturing technology in the hope of impacting the career choices of their students. The crucial topics covered in the workshop included CAD modeling, rapid prototyping, and lean manufacturing.[37] Since industrial representatives interacted with participants during the workshop as well, it is a fair assumption to conclude that some of these topics and the corresponding concepts would be beneficial to students. Hence these topics are included in our curriculum module, as outlined in Chapter 4.

Project Lead the Way also provides several engineering curricula with several specialized courses. One relevant course is Computer Integrated Manufacturing. The very topic emphasizes the fact that computers have become part and parcel of manufacturing over the last two decades. The course is one year long and is broken down into five different units. Each unit and the corresponding concepts are summarized in Appendix A. A review of the course shows that, although it covers a wide range of concepts on manufacturing in detail, it does not give much information about all types of manufacturing processes. It does make the student proficient in Computer Integrated Manufacturing programming and gives them a concrete foundation on the concepts of manufacturing, such as dimensioning, tolerances, materials, automation, cost, flowcharting, prototyping and accuracy. These are important concepts that could be included in our curriculum module as well. On the other hand, the curriculum did not demonstrate the difference between additive and subtractive manufacturing processes, consider when one manufacturing approach is better than the other, or identify the different classifications of subtractive manufacturing and additive manufacturing. Furthermore, the course does not discuss the different parameters that affect each manufacturing process, or methods and tools that can be employed to choose one manufacturing process over another. These potential shortcomings were addressed in the curriculum module we developed.

CHAPTER 3: Methodology for Design of the Curriculum

3.1 Knowing and Learning

Although at first glance they both might seem like synonyms, knowing and learning are entirely different concepts and have different methodologies. On taking the course on Knowing and Learning from Dr. Susan Empson of the College of Education at The University of Texas at Austin, significant insights were gained which proved to be of great use during the development of the curriculum module. The most important lesson from the course was that, in order for a curriculum to be effective, it must facilitate the right approach in the student's education. The approach serves as the foundation for this curriculum. Just like a great building with a weak foundation is bound to fail, a curriculum framework built with a weak approach would not be effective in educating students.

3.1.1 Types of Learning

According to Leite et al.,[38] one of the most widely used systems to describe varying learning methods is a model developed by Neil D. Fleming. Fleming proposes that there are four major types or styles of learners: visual, auditory, reading-writing preference and tactile or kinesthetic learners. The so-called VARK model expands on earlier neuro-linguistic programming models while stressing the development of curricula based on these learning styles. Fleming proposes the resulting curricula will prove to be beneficial for the entire classroom, which can be assumed to be a mixture of these four learning styles.

Fleming suggests that visual learners think in pictures, so for these learners, curriculum elements should include methods of idea representation such as diagrams, pictures, charts, and other graphic representations, creating visual reinforcement for key concepts.[38] Likewise, he proposes that auditory style learners are most successful in an academic setting in which auditory elements, like lectures, discussions or discussion sections, tapes and even music, are used as part of the curriculum. Tactile learners prefer experience-based learning methods like moving, touching, active exploration, projects and experiments. The reading-writing learner not surprisingly shows a preference to written material.[38] The VARK model's use in instruction allows teachers and curriculum developers to prepare classroom and follow-up materials that provide a path to understanding key concepts for all four styles of learners. Additionally, it has been noted that students can also use the VARK model to identify their personnel preferred learning style, in theory allowing more effective studying.

3.1.2 Approaches to Learning

Several approaches to learning have been developed over the years. Cognitive science plays an important role in improving the learning of the student. Before we delve into the approaches it is important to understand the difference between knowing something and knowing about something. There are several courses every adult will have completed during their education. Some courses, like Geography, do not remain in the memory or the picture is vague. On the other hand, there are some courses which leave an everlasting impact and still remain etched in our brains. It could be that the course was taught by a teacher who was the student's favorite. If we delve deeper, we might find that the teacher followed a much more effective approach to teaching that facilitated the learning of the student. The most common approaches in the science of learning are classified as Deep and Surface approaches. The most common traits and processes of the approaches are directly quoted in the Table 1 below.[39]

Deep Approach	Surface Approach
Relates to ideas of previous knowledge and experience.	Treating the course as unrelated bits of knowledge.
Looking for patterns and underlying principles.	Routinely memorizing facts and carrying out procedures.
Checking evidence and relating it to conclusions.	Focusing narrowly on the minimum syllabus demands.
Examining logic and argument cautiously and critically.	Seeing little value or meaning in the course or set tasks.
Memorizing whatever is essential to understanding.	Studying without reflecting on either purpose or strategy
Monitoring understanding as learning progresses.	

Table 1: Common traits and processes of Deep and Surface Approach[39]

If we look at the summed up characteristics of both approaches, it is clear that the deep approach is a much stronger approach to learning and is justified as the basis for the new curriculum that we designed. According to Entwistle and Peterson, "When the emphasis is on the retention of information without any cognitive reorganization, then 'knowing' is the word used."[39] This is a consequence of the Surface approach. Learning is expected to be facilitated if the educational content presented to the student promotes cognitive organization of the information studied.[40]

3.1.3 Approaches to Teaching

Teaching and learning are very closely connected with each other. Just as there are different methods, styles and approaches to learning, so there are different methods, styles and approaches to teaching. At the very highest level, teaching theories can primarily be divided into two broad categories or "approaches" — teacher-centered and student-centered:

Teacher-Centered Approach to Learning

As the name suggests, this style of teaching is centered on the teacher. The course instructor is the main expert and information is transferred from teacher to student though lectures, assignments and other traditional forms of direct instruction. In a sense students are viewed as "empty vessels" to be filled,[41] where the information is received in a passive manner. In this approach the teachers' ultimate goal is preparing the student to excel in tests. In this teacher-centered model, teaching and assessment are viewed as two separate entities.

Student-Centered Approach to Learning

In the Student-Centered model, teachers are still authority figures; however, both teachers and students expect to play equally engaging roles in the process of learning. In contrast to the Teacher-Centered model, the teacher's primary role in the Student-Centered model is redefined as a coach or facilitator, with the goal of helping the student achieve overall comprehension of the material.[42] Student learning is quantified through both formal and informal forms of assessment, including group projects, student portfolios, and class participation.

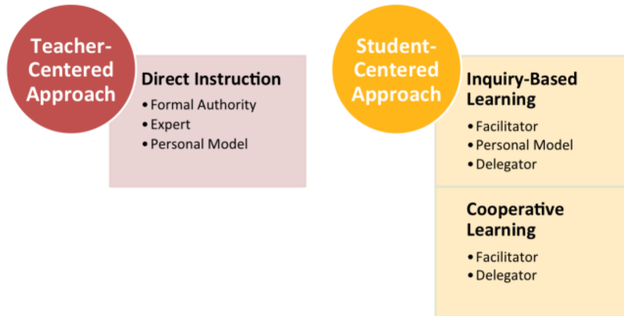

Figure 3: Teaching approaches and methods [41]

3.1.4 Methods of Teaching

Underneath the overall headings of Student- and Teacher-Centered approaches, we can further classify teaching methods. This is not to be confused with teaching styles. Teaching methods are not surprisingly the methods used to deliver content to the student in the classroom. Figure 3 shows the hierarchy of methods under the broader classifications of Student-Centered and Teacher-Based approaches. Again, this is not be confused with the teacher's individual style, which will vary. The methods allow for expression of the instructor's individual style in the classroom while utilizing tools with proven methods and methodologies for the maximum and efficient delivery of the content.

The Teacher-Centered approach is based on a method labeled "direct instruction". This typically is what one thinks of as the older or conventional way of teaching. In this work, however, we are more interested in examining, and will limit our discussion to, the methods associated with the Student-Centered approach. The methods under the Student-Centered approach are Inquiry-based Learning, Cooperative Learning and Project-based learning.

1. Inquiry-Based Learning:

The Inquiry-based Learning method is also referred to as "Learning by Discovery".[44] This methodology concentrates on the student investigating and learning through hands-on practices.[44] The primary role of a teacher in this form of learning is to provide guidance and support to the students during the learning process, where the students play an important role in their self-education. This is a very active learning process. It is also similar to a very popular education teaching strategy called instruction scaffolding[46], where the teacher allows the students to come to their own conclusions with minimum input.

In this method, the learning depends greatly on the facilitator; learning is seen as a symbiotic process and communication is two way. Students explore various concepts through practical hands-on activities that invoke Kinesthetic Learning. Research has shown that instruction methods that are more stimulating than auditory learning (for example, kinesthetic learning) are more likely to enhance learning in a heterogeneous student population. [47]

2. Cooperative Learning:

The Cooperative Learning method is based on team work. It is often said TEAM stands for "Together everyone achieves more". In the classroom context the Cooperative Learning method refers to a teaching methodology and a set of classroom management techniques that emphasize working together and a strong sense of community[21]. This model's intent is to foster students' academic and social growth. It uses teaching techniques such as "Think-Pair-Share"[48] and reciprocal teaching. Again, like Inquiry-based Learning, Cooperative Learning is considered a Student-Centered approach since learners take responsibility for their learning and development. Interacting and learning alongside fellow class students is the focus of this method of instruction.

3. Project-based Learning:

This method can been seen as an extension of Inquiry-based Learning. However, it differs in that there is more emphasis on hands-on activities. Project-based Learning (PBL) is a dynamic classroom approach in which students explore real-world problems and challenges in an active manner and acquire a deeper knowledge for solving them. It is sometimes even referred to as "learning by doing". Confucius and Aristotle were early advocates of learning by doing.[49] Socrates' model is based on "questioning, inquiry, and critical thinking to aid the process of learning".[49] These strategies have stood the test of time and remain very relevant even in today's PBL classrooms. Project-based Learning may also be cooperative, thus promoting active and engaged learning.

It is evident that the manufacturing curriculum should be based on certain proved methodologies and approaches to be successful. It must have an end goal of achieving a deep approach. The learning must be active and the approach must be Student-Centered, using teaching methods that facilitate this learning approach. A combination of Inquiry-based, Project-based and Cooperative Learning must be developed. The curriculum must have a fair share of auditory, visual and kinesthetic activities to cater to the widely-varied learning styles of students. When used in combination, these approaches provide a concrete foundation for the curriculum.

3.2 Framework for the Curriculum

These different approaches for teaching and learning can be used to create a curriculum framework. A framework provides a skeleton structure and acts like a template to form the curriculum. Of the various frameworks available, the most widely used is the one developed by Wiggins and McTighe called "Understanding by Design".[50] According to the authors, "Over 250,000 educators own the book and over 30,000 Handbooks are in use".[50]Understanding by Design, or UbD, is a tool utilized for educational planning focused on "teaching for understanding".

According to Ubd, "Teachers traditionally start curriculum planning with activities and textbooks, instead of identifying classroom learning goals and planning towards that goal".[50] Backward design is the process advocated by Wiggins and McTighe to be followed when designing a curriculum. In backward design, the teacher first defines what the classroom outcomes are and then plans the curriculum, thus choosing activities and materials that will help determine the student's ability and facilitate student learning. This approach breaks down the entire curriculum into smaller chunks called units. Each unit is designed via a template in three main stages.[50] We adopted this approach for designing the curriculum module, as shown in Chapter 4. The concepts and performance tasks in Chapter 4 were designed with the end goal in mind.

CHAPTER 4: The Curriculum Module

The curriculum module described in this chapter was designed by adopting the tried and tested methodologies and approaches and the Understanding by Design (UbD) framework. Interactive course content with hands-on experience is the key to the success of this curriculum. Before describing the curriculum in detail, let us review the requirements and constraints for the curriculum.

4.1 Customer Needs Analysis

The main goal of this curriculum module is to teach manufacturing in a manner that is accessible to all schools which do not have access to state-of-the-art facilities and manufacturing equipment. The customer needs are based on interviews with Mr. Evans of Bowie High School, Austin, TX. Bowie is a good model for the population of schools we are targeting. The interviews with Mr. Evans produced the following customer needs:

- Curricula most often than not is very verbose. Hence, an important need is to make use of graphics in the curriculum. This is an important strategy for keeping students engaged. Remember, "A picture is worth a thousand words."
- The curriculum could have illustrative videos. This will facilitate the teachers' understanding. Most teachers are not familiar with manufacturing equipment and it is difficult to communicate concepts that are beyond their expertise.
- The curriculum must clearly state the cost and timeframe for every week. Costs are sometimes overlooked. As far as possible, try to recycle the materials. This way purchases can be viewed as investments rather than expenditures.
- Make judicious use of the materials to minimize the mess. Most importantly, minimize waste.
- Any activity which takes more than an hour to set up will probably not be adopted. Teachers are the gatekeepers for the curriculum module and there is a "time to reward" ratio which must be evaluated. For example, if an

activity takes 15 minutes to set up as opposed to one hour, the shorter setup time is highly preferred.

- More emphasis should be placed on hands-on activities. This will facilitate student understanding of the manufacturing processes.
- The cost per student for six weeks should be no more than $20 per student for a class of 20-24 students.

Requirements and Constraints

Based on the customer needs analysis, the following specification sheet was developed.

REQUIREMENTS	CONSTRAINTS
Curriculum should not be verbose and should provide vivid graphics. Video for capstone project is a plus.	The timeframe for the module must not exceed 6 weeks in length.
Clean-up time after any learning activity must be minimized.	The cost for implementing the curriculum should not exceed $20 per student for a 25 member class for the 6 week module.
Cost and timeframe must be clearly stated for every unit.	
Setup time should be minimized for each activity.	
Focus on hands-on learning activities.	

Table 2: Requirements and Constraints for the Curriculum

4.2 Manufacturing Processes

Since the overall goal of this curriculum is to give students a complete overview of manufacturing processes, this was the starting point, as dictated by the UbD approach. The following concept map was developed to organize the manufacturing technologies addressed in the curriculum from the traditional subtractive manufacturing techniques to the state-of-the-art advanced additive manufacturing.

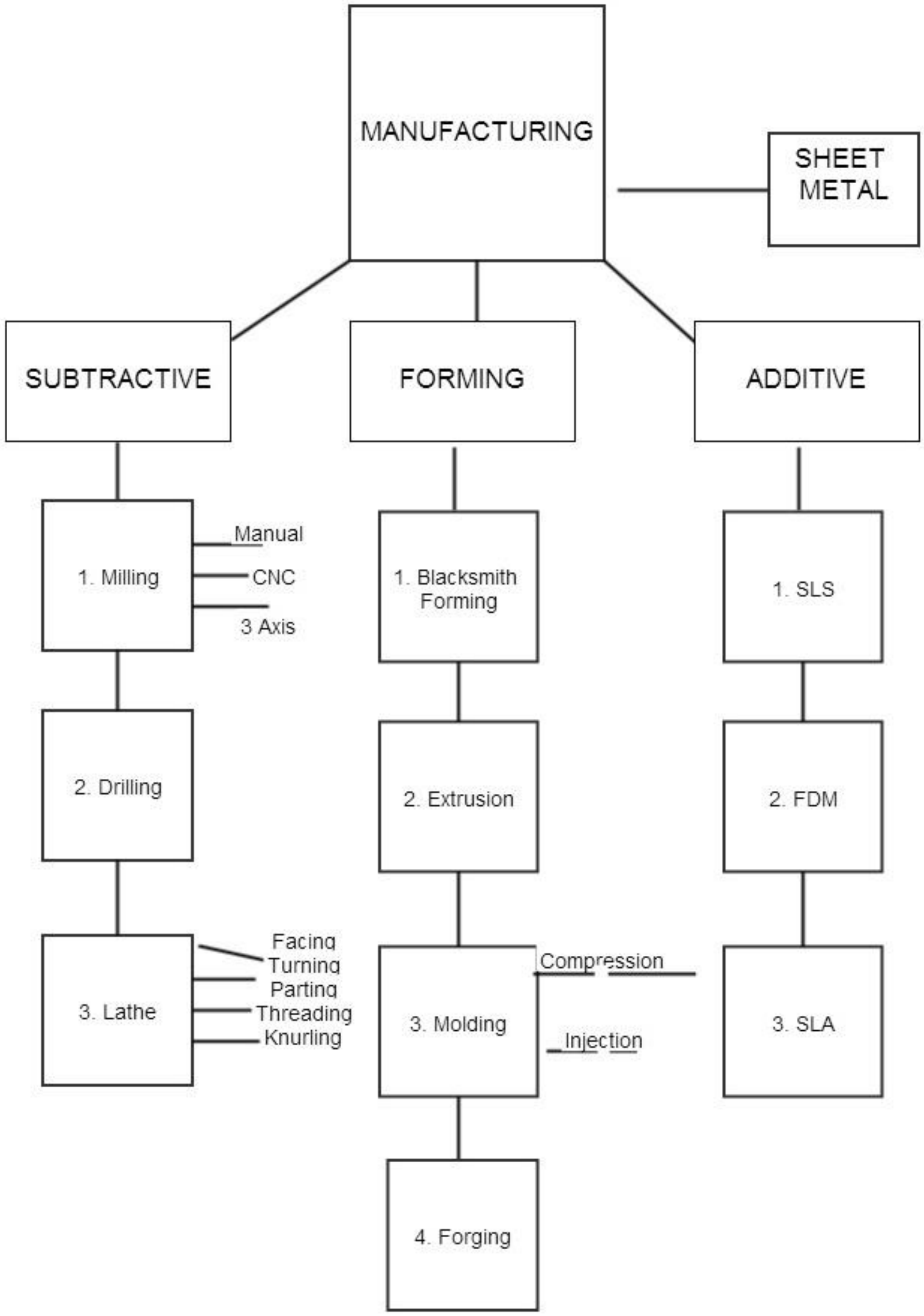

Figure 5: Concept map of manufacturing processes in the curriculum.

There are several concepts which the student needs for a deep understanding of the different manufacturing processes. These concepts depend on the objectives of the curriculum, which are defined in the following section.

4.3 Objectives of the Curriculum

The list below provides details on the objectives of the curriculum module. These were developed as the first step of the UbD approach.

- The student will understand the history, important milestones, and economic impacts of manufacturing.
- The student will have an understanding of the different manufacturing processes widely used in the industry.
- The student will have an understanding of how common, familiar products are made.
- The student will provide rationale explaining why certain manufacturing processes are better than others for a given type of product.
- The student will develop an understanding of the use of different materials for manufacturing and their selection criteria.
- The student will used structured decision-making tools, such as decision tree analysis.
- The student will be able to describe the role of manufacturing in meeting the consumer's needs, wants and expectations
- The student will understand the strategies for making tradeoffs and for optimization.
- The student will be able to distinguish the various parameters that affect production time and quality of end products.
- The student will have an understanding of Computer Integrated Manufacturing.
- The student will understand the various career paths available in manufacturing and will be familiar with the educational requirements for these careers.
- The student will understand the basic principles underlying manufacturing production.
- The student will demonstrate the ability to use elementary tools to produce a manufactured product to given tolerances.
- The student will demonstrate an awareness of quality control measures.

- The student will demonstrate an understanding of Standard International (metric) and US customary units of measurement.
- The student will demonstrate an understanding of basic safety techniques and responsibilities during manufacturing.
- The student will develop interpersonal and presentation skills.

4.4 Overview of the Curriculum

Let us now delve into the concepts to be taught in the curriculum. The length of the curriculum is six weeks. It is broken down into units. Each unit may vary in length based on the depth of the content presented. As discussed earlier, not all of the concepts are taught at once. The key is to integrate selected concepts during the learning of the different manufacturing processes. This contributes to student engagement and effective time management. The layout of the units is discussed below.

Unit 1: What is manufacturing and why do we need it? (Time: 1 week)

Lesson 1.1 Overview of Manufacturing

Concepts addressed in the lesson:

1. Manufacturing is critical to the economy.
2. Evolution of manufacturing and its impact.
3. Careers associated with manufacturing.
4. A product may be created with more than one manufacturing process using different materials.

Performance Tasks

The students are required to:

1. Discover manufacturing through researching online sources and the "How It's Made" series on the Discovery Channel.
2. Research a particular product and discuss the process by which it is made. Develop an individual presentation and present findings to the class. (The length of the presentation may vary depending on the number of students in the class)
3. Explain the evolution of manufacturing graphically.

Lesson 1.2: Introduction to Manufacturing

Concepts addressed in the lesson:

1. Manufacturing is a series of interrelated activities and operations that involve product design, planning, production, materials control, quality assurance management, assembly and marketing of a product.
2. Customer needs analysis using recognized marketing research techniques (interviews, surveys, online research, etc.) and identifying what the consumer wants with demand and wishes.

3. Overview of safety in manufacturing.

Performance Tasks

Students are required to:

1. Engage in an activity to understand the needs of customers before manufacturing a product. Application of recognized market research techniques.
2. Conduct an interactive quiz on safety for the students. This is conducted by the students for the students.

Lesson 1.3: Basics needed for Manufacturing.

Concepts addressed in the lesson:

1. Strength of materials must be understood qualitatively, e.g., understanding the difference between hard, soft, brittle and ductile materials.
2. Quality control is a key process in manufacturing. Overlooking quality control can lead to catastrophes.
3. Jigs and fixtures are vital in maintaining consistency and quality control.
4. Knowledge of measurement, calibration, accuracy, precision and tolerances, and difference between SI and metric units.

Performance Tasks

Students are required to:

1. Bring samples each of hard, soft, brittle and ductile materials to present to class.
2. Complete a hands-on activity with Go-No go gauging to demonstrate understanding of the concept.
3. Complete photo assignment on jigs and fixtures.

Unit 2: Introduction to Manufacturing Processes (Time: 1 week)

Lesson 2.1 Design for Manufacturing.

Concepts addressed in the lesson:

1. Design for manufacturing – manufacturing must be considered as part of the design process.
2. Material properties must be considered as part of the design process.
3. Analysis of case studies on previous manufacturing failures as a way for engineers to avoid failures in the future.
4. Reverse engineering and its potential benefits for manufacturing.

Performance Tasks

Students are required to:

1. Present (in teams) a one-page report on an interesting case study of a manufacturing failure.
2. Disassemble and analyze a simple product to understand the concept of Reverse Engineering.

Lesson 2.2 Types of Manufacturing Processes.

Concepts addressed in the lesson:

1. Difference between additive and subtractive manufacturing.
2. Understanding the mechanism by which material is removed from stock.
3. Classification of subtractive manufacturing processes.
4. Classification of additive manufacturing processes.

5. Classification of forming – is forming additive or subtractive manufacturing?

Performance Tasks

Students are required to:

1. Prepare an individual concept map on types of manufacturing processes.
2. Complete a hands-on activity for demonstrating the mechanics of material removal using a foam block and X-ACTO® knifes.

Lesson 2.3 How Conventional Manufacturing Works

Concepts addressed in the lesson:

1. The process of material removal in subtractive manufacturing.
2. Heat generation due to friction and control of temperature during manufacture.

Performance Tasks

Students are required to:

1. Brainstorm different ways to control the temperature during manufacture.

Lesson 2.4: Computer Integrated Manufacturing.

Concepts addressed in the lesson:

1. Mass production is used when there is a set of repetitive steps involved in making large numbers of a given product.
2. Robots are used to perform diverse functions and work in diverse environments.
3. Computers have distinct advantages over humans in some industrial settings (e.g., hazardous environments, repetitive motion, or long hours).
4. The technique of "handshaking" is used to allow robots and other machines to communicate and coordinate their activities smoothly.

Performance Tasks

Students are required to:

1. Complete a photo assignment on mass-manufactured products where robots are possibly used.

Unit 3: Subtractive Manufacturing (Time: 1 week)

Lesson 3.1 Milling and Drilling

Concepts addressed in the lesson:

1. The difference between milling and drilling.
2. The history of the lathe.
3. Knowledge of the tools required for milling.
4. CNC milling and the tolerances it can achieve.
5. 3-axis milling and its automation.

Performance Tasks:

Students are required to:

1. Complete a hands-on activity using a Dremel® tool and laser engraver.

Lesson 3.2 Lathe

Concepts addressed in the lesson:

1. Definition and construction of a lathe.
2. Examples of common objects that were made on a lathe.

3. The difference between two of the most basic operations, facing and turning.
4. The process of threading, with examples.
5. Left-hand and right-hand threads and their uses.
6. The process of knurling.

Performance Tasks:

Students are required to:

1. Participate in a demonstration activity on a lathe (or lathe model).
2. Complete a quiz on the basics of lathes and lathe operations.

Unit 4: Forming (Time: 3 days)

Lesson 4.1 Introduction to forming.

Concepts addressed in the lesson:

1. The mechanism of forming.
2. Scenarios where forming is advantageous.
3. Process parameters and costs of forming.

Lesson 4.2 Blacksmith Forming

Concepts addressed in the lesson:

1. History of blacksmiths and their impact on weapons development and the industrial revolution.
2. Process parameters for forming, such as heat and force.
3. Costs associated with forming

Lesson 4.3 Extrusion

Concepts addressed in the lesson:

1. Mechanisms of extrusion and evolution of the process (and its use in restaurants!).
2. Materials that can be extruded.
3. Factors that affect the quality and finish of extruded products.
4. Automation of extrusion.

Performance Tasks

Students are required to:

1. Complete a hands-on activity to understand extrusion – make clay strings using a Play-Doh® syringe extruder.

Lesson 4.4 Molding

Concepts addressed in the lesson:

1. Mechanisms of molding, casting, pattern making
2. The history and evolution of molding.
3. Difference between compression molding and injection molding.
4. Knowledge of the key terms, such as pattern, riser, runner, cooling time, etc.
5. The impact of molding on mass production and how it is achieved.
6. Introduction to allowances, such as shrinkage allowance, draft allowance, finishing or machining allowance, shake allowance and distortion allowance.
7. Materials that are commonly molded.
8. Costs involved in molding.

Performance Tasks

Students are required to:

1. Complete a hands-on activity on molding – demonstrate the use of a cookie mold using modeling clay.
2. Complete a photo assignment on commonly molded objects.

Lesson 4.5 Forging

Concepts addressed in the lesson:

1. Definition, history and evolution of forging.
2. Mechanism process parameters of forging.
3. Common applications of forging in everyday products.
4. Material and tooling costs for forging.

Performance Tasks

Students are required to:

1. Complete a hands-on activity on forging – demonstrate forging using modeling clay and simple shaped molds.
2. Prepare an estimate for material and tooling costs required for a forging example.

Unit 5: Sheet Metal Forming (Time:2 days)

Lesson 5.1 Basics of Sheet Metal Forming

Concepts addressed in the lesson:

1. The concept of malleability in materials.
2. Is sheet metal forming an additive or subtractive manufacturing process?
3. Commonly used tools for sheet metal forming.
4. Materials and tooling costs for sheet metal forming.

Performance Task

Students are required to:

1. Complete a hands-on activity – make an envelope using cardboard and scissors, mimicking the sheet metal and snips used commonly in industry.

Unit 6: Additive Manufacturing (Time: 1 week)

Lesson 6.1: Introduction to Additive Manufacturing.

Concepts addressed in the lesson:

1. Why is there so much hype around 3D Printing?
2. Prototyping and how it has revolutionized product design and development.
3. Key advantages and limitations of additive manufacturing.
4. Time, cost and labor required for additive manufacturing.

Performance Tasks

Students are required to:

1. Complete a video assignment on the latest trends in 3D Printing.
2. Complete a quiz on the advantages of additive manufacturing.

Lesson 6.2: 3D Printing & Fused Deposition Modelling

Concepts addressed in the lesson:

1. Mechanism of 3D Printing.
2. Process of fused deposition modeling and its similarities to extrusion.

3. An introduction to commercially available tabletop FDM printers.

Performance Tasks

Students are required to:

1. Complete a hands-on activity on 3D printing using 3Doodler 3D Printing pen.

Lesson 6.3: Selective Laser Sintering

Concepts addressed in the lesson:

1. Qualitative physics of powder sintering.
2. Build direction and scanning patterns.
3. Advantages of Selective Laser Sintering (SLS) process.
4. Materials choices for SLS.
5. Introduction to Direct Metal Laser Sintering.

Lesson 6.4: Stereolithography

Concepts addressed in the lesson:

1. Qualitative physics and chemistry of solidifying photosensitive resins.
2. Build direction and scanning patterns for Stereolithography (SLA).
3. Advantages of SLA process.
4. Materials choices for SLA.

Performance Tasks

Students are required to:

1. Review pictures of objects made with different additive manufacturing processes and identify the process with which each was made.

Unit 7: Capstone Project (Time: 1 week)

Concepts addressed in the lesson:

1. Teamwork and collaboration in manufacturing.
2. Hands-on skills, dexterity and creativity involved in manufacturing.
3. Application of concepts previously learned, such as tolerance, waste, material choice, quality control, etc.
4. Practice of the common principles of manufacturing processes, such as assembly, lines and work cells, via integration of the parts produced for a finished product.

Performance Tasks

Students are required to:

1. Work in teams to fabricate a product using the mini-lathe (described in Chapter 5), such as drumsticks or a wand.
2. Make an iPhone or an iPad stand using the mini-lathe and rubber bands.

CHAPTER 5: Capstone Project

The capstone project is sometimes referred to as a capstone experience, culminating project, senior exhibition, etc., among other names used.[55] According to the glossary of education reform, a capstone project is defined as "a multifaceted assignment that tests the student across various concepts thus serving as an intellectual experience for students, typically during their final year of high school."[55] Capstone projects[56] also help teachers to incorporate engineering principles in classrooms. Such a project is analogous to a research project in a broad sense but differs because the solution is open-ended. We adopted this approach in our curriculum to encourage students to think critically, solve intriguing yet challenging problems, and develop skills such as experimentation and prototyping, oral communication and public speaking, goal setting, research skills, media literacy, teamwork, project planning and creativity. A capstone project also serves as a good performance task towards the end of the curriculum to assess the students' knowledge on the various domains of manufacturing. We tried to connect the theme of the project to real student needs. At the demonstration session at Bowie High School, the students showed interest in a magic wand or a drum stick.

Of the several hands-on activities, the best was saved for the last. The capstone project involves designing and manufacturing a product with a miniature desktop wood lathe which is assembled by the students. This chapter describes design and development of the mini-lathe for this capstone project.

5.1 Problems with Existing Lathes

There are no intrinsic problems with commercially available lathes. They quickly manufacture goods with high quality and precision. However, they are expensive and require specialized training to operate. A conventional lathe forms the backbone for understanding manufacturing, and a hands-on experience with a lathe is a demand for our curriculum. MIT offers online videos on the operation of lathes and other machine tools,[25] and these may be a good solution for schools with limited finances. However, Mr. Evans of Bowie High School said that students tend to lose engagement during the process of watching videos. Thus, the requirement was to at least simulate a lathe in a live experience so the students can observe its basic operation. Additionally, providing students with the experience of making a product with their own hands can only deepen their knowledge of manufacturing concepts.

5.1.1 Analysis of Existing Lathes

The first step was to benchmark the cost of mini-lathes available on the market. The price of a lathe depends on its operation and purpose. Although complex operations such as threading can be performed on some high end mini-lathes, our goal is to design a lathe to give the student a firm grasp of the fundamentals of machining. The cost also depends on the type of material the lathe is capable of processing. Different materials, including metal, wood, plastics and even composites, can be turned on a lathe. Since our goal is not to manufacture a high-end product with high strength, any material which reduces the cost of the lathe is preferred.

Based on commonly used materials, lathes can be broadly classified as metal lathes and wood lathes. Of the several desktop metal lathes considered, the Shop Fox® M1015 6" x 10" Mini Metal Lathe made by Woodstock International, Inc. (Bellingham, WA) is a good option for our curriculum. It does not include a thread-cutting kit. This lathe retails for $740.[58] Some key specifications are shown in the Table 3. Other metal lathes average around the same price and have high end features such as a powered carriage, rugged construction, variable spindle speed, etc. A list of the lathes with details that were considered is shown in Table 4.

SPECIFICATIONS	
Motor:	1/5" HP, 110V, single-phase
Swingover bed:	6"
Distance between centers:	10"
Cross slide travel:	2-3/8"
Spindle bore:	3/8"
Spindle speed:	100-2000 RPM
Approximate shipping weight:	106 lbs.

Table 3: Specification sheet for Mini Metal Lathe.[58]

Make and name of metal lathe	Price in US$	Key Specs
Grizzly G8688	574	Variable speed, 16 TPI Reversible Lead screw and Chip Tray.
RIKON 70-100 12” x 16”	420	Laser engraved ram with 2-1/2-Inch travel, 1/2HP Motor and ability to add multiple extensions.
Generic 7” x 12” Mini Metal Lathe	600	Swing Over Bed: 7" , Chuck Diameter: 3.15" Distance between center: 12"/8"

Table 4: Key specifications and prices of other metal lathes considered.[45, 51, 52]

The next type of lathe benchmarked was a wood lathe. The average pricing on a desktop wood lathe is considerably cheaper than a metal lathe as the construction is not as robust. A good option for our purposes is the Central Machinery (Harbor Freight Tools, Calabasas, CA) 8 in. x 12 in. 1/3 HP Benchtop Wood Lathe, which retails for $125 online. Note that this product received negative reviews for its poor design and strength.[43] The specification sheet for this product is given below.

SPECIFICATIONS	
Motor	1/3 HP, 110V, single-phase
Distance between centers:	12"
Tool rest size (in.):	4", 7"
Spindle bore:	3/4"
Variable speed:	750-3200 RPM

Table 5: Specification sheet for Mini Wood Lathe.[43]

These options are good for providing a hands-on experience. Since there is an average of 20 students in the class, teams of four will require five lathes. This represents an investment of over $3000 for metal lathes and over $600 for wood lathes. This exceeds the budget allotted for the project. Hence, scalability is not feasible with commercially available lathes.

Another option is a do-it-yourself (DIY) kit for a wood lathe. Constructing a lathe from a kit has a lot of merits. The students not only manufacture products on the lathe, but they manufacture the lathe itself. The abilities of the students and teachers are limiting, however, as they are likely highly variable. Since time is very limited, there is little room for error. Any mistake made the students will jeopardize the possibility of completing the capstone project. Many teachers will not have time to manufacture five lathes. However, once constructed by those teachers that can, the lathes are available for subsequent classes.

A good online source of DIY projects is Instructables.com, which has the instructions for building a mini-lathe based on project from ShopNotes magazine.[59] Although the original plan is not available for free, one user uploaded a simple nine step plan to make this mini-lathe to Instructable.com. The plan has simplified steps but is not recommended for inexperienced DIYers. Construction is complicated, a motor must be mounted, belts must be aligned, bearings must be mounted, headstock parts must be cut carefully with a band saw, etc. This might be a good assignment for an intermediate level DIYer but quite daunting for a beginner. The strengths and weaknesses of the lathes discussed with regards to our application are tabulated in Table 6.

Type of Lathe	Strengths	Weaknesses
Mini Metal Lathe	• Durability • High precision • Portable	• Very expensive • No student involvement in lathe construction
Mini Wood Lathe	• Portable • Low cost	• No student involvement in lathe construction
Do-it-yourself Lathe	• Low cost • For high achievers	• Time intensive • Skill level high

Table 6: Strength & Weakness Analysis during market research

5.2 Design of the Desktop Mini-Lathe

The design of the mini-lathe for the capstone project is based on the requirements and constraints established from benchmarking. The strengths of the existing products serve as inspiration and the weaknesses are addressed by design improvements. To simplify the design and reduce costs, the lathe is powered by a common power drill. Additionally, other basic requirements and constraints arose from customer needs analysis. The specifications for the mini-lathe are given in the Table 7 below.

Requirements	Constraints
Portable	Cost not to exceed $50
Plywood construction	Construction time not to exceed 3 periods
Dust collection mechanism	Construction with simple tools
Significant student involvement	Weight no more than 20 lbs
Safe for construction and operation by high school students	

Table 7: Requirements and Constraints for the desktop mini-lathe's design

5.2.1 Design Decisions

Most of the requirements and constraints are quite straightforward. The completed mini-lathe must weigh no more than 20 pounds based on the backpack weight limit recommended by the American Academy of Pediatrics. According to them, it is harmful to the students if their backpacks weigh more than 10% to 20% of their body weight.[57] On average, sixteen-year-olds girls in the fiftieth percentile weigh 115 lbs.[60] This provides a conservative specification, as boys tend to weigh more than girls. Based on 17.5 % of the girls' weight, the maximum weight of the mini-lathe is 20.125 lbs, which rounded down gives 20 lbs. Plywood was chosen as the material as it offers very good strength for our application and weighs less than steel. The dust collection mechanism is needed to allow collection of the sawdust that results from machining. Since it is the responsibility of the teacher to ensure cleanliness, time spent on cleaning must be kept to a minimum. So a separate compartment was designed in the mini-lathe to collect the machined waste, simplifying the disposal process.

The third decision was fixing the distance between centers. This distance was set at 18 inches based on the average length of a human forearm, which is 18 inches.[61] Since the lathe must be portable, the length should not be excessive. Based on these design parameters, the lathe was built using simple tools, including a handsaw, a drill and a power screwdriver. For enabling the user to hold and guide the turning tool safely with minimal effort, a guide rail was designed as a support. A CAD model of the mini-lathe is shown below.

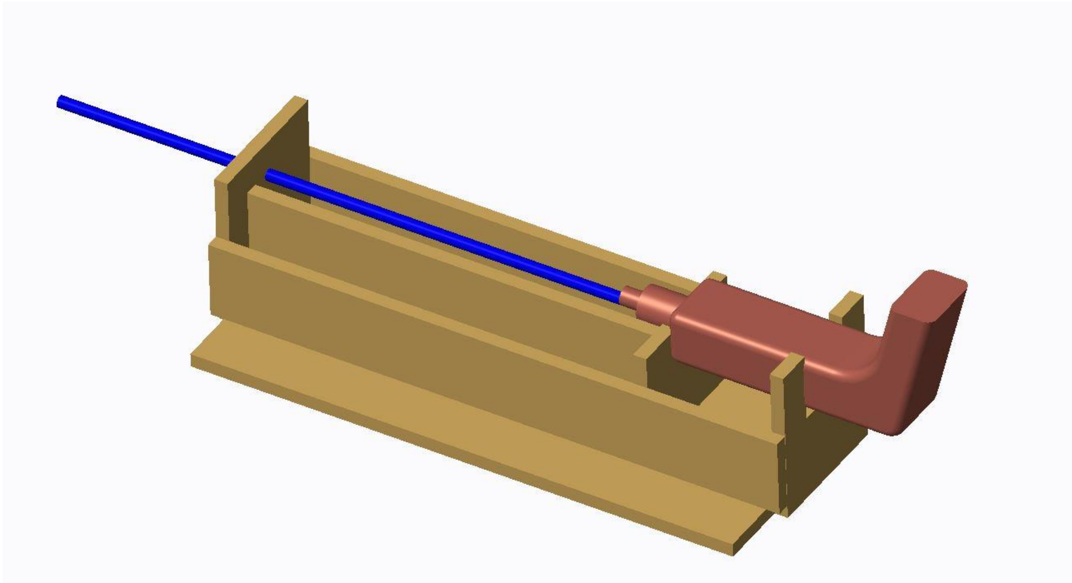

Figure 7: Computer CAD model of the mini-lathe.

5.2.2 Make and Take Kits

Since we were limited by time and the curriculum requires student involvement in the building of the lathe, the student activity was optimized by designing a simple kit. The lathe has five plywood parts cut with a miter saw. They are simple 90° square cuts. These can be cut by a teacher with minimal experience or precut wood can be purchase from a building supply store. This will prevent accidents and eliminate the need for safety training classes on power tools.[62] Only two plywood parts of the five require a profile to be cut for mounting the drill. The profile can be cut with a portable jig saw. Although the semi-circular profile is tricky and ideally should be cut with a band saw, we developed a very easy way to create it. The students can use a holesaw, which produces a circular hole. They then trim off the extra cross section using a handsaw. This leaves a semi-circular cross section. A common handsaw and a hole-saw are shown in Figures 8 and 9. The prototype lathe is powered by a HILTI UH 700 ½" Hammer Drill. This removes the need for a motor mount, belt mechanism, etc. Drills often have variable speed settings. For our given operation, a high speed drill was chosen, as we wanted the removal of material to be dramatic so that the students develop a better understanding of the material removal process. Cordless drills, although cheaper, are not ideal for this application as they do not perform well enough. They are, however, good for drilling holes and screwing the plywood pieces together. The entire process was also made into a detailed video and uploaded on YouTube. The URL is given in Appendix D. The bill of materials and dimensional drawings are in Appendix E.

Figure 8: Typical handsaw used for creating the various profiles[63]

Figure 9: A hole saw used for creating the various profiles[64]

CHAPTER 6: Verification and Validation of the Curriculum

6.1 Definition of Verification and Validation.

Since our research is focused on developing a new engineering curriculum module, it seems reasonable that we use established engineering procedures such as verification and validation. According to Fraenkel, "Verification and validation are independent procedures that are used together for checking that a product, service, or system meets requirements and specifications and that it fulfills its intended purpose"[65]. These are key components in a quality management system such as ISO 9000.[65] Although ISO 9000 is typically used for products and is intended to increase business efficiency and customer satisfaction, these standards share the same purpose and goal for the curriculum developed. The objective of ISO 9000 is to use a quality management system to increasing productivity, reducing unnecessary costs, and ensure and document the quality of processes and products. [65] These same goals are valid and desirable for curriculum development as well. In other words, the product or curriculum must meet the needs of the customer. Since in this case the customers are students and teachers, we developed a model to test the curriculum with the customers.

6.2 The Need for Validation

Validation is a key element in research that bridges the gap between what we predict and what the actual results are. One of the problems in research is that the scope is so broad and things may be overlooked, which may lead to errors during execution. Thus, validation proves imperative. A concept or a curriculum can be pilot tested using a base model. This serves as a feedback mechanism to direct improvement of the curriculum. Just like an engine can be calibrated for optimal performance, the curriculum can be tailored based on feedback received from students and teachers.

Validation also sets a benchmark for research. One of the challenges in education research like this is to quantify the evaluation results. It is easy to qualitatively assess an element in research. However, qualitative assessment is relative and varies from person to person when there is no standard or benchmark for a good curriculum. Quantitative validation eliminates this issue by establishing a strong rationale for directing the curriculum development effort.

6.2.1 Developing a Model for Verification and Validation

One of the prerequisites for verification and validation is that the product must be tested by a third party. In some sense this is similar to the process of third-party verification (TPV). A central premise of TPV is that validation must be conducted by someone other than the developer to avoid conflict of interest. The customers in this case are the students and the teachers. Therefore, the model adopted for this research is based on soliciting feedback from students via a sample curriculum module delivered by their teacher.

To obtain quantitative feedback, a pre-test and post-test strategy was adopted. A randomized pre-test/post-test study is suggested by Franekel, Jack and Norman [65]. The study is randomized to avoid bias. During evaluation it is possible that the grader might know which of the answers are from the pre-test and which of the answers are from the post-test. Furthermore, the name of the student may cause the individual to be partial in some way during grading. To eliminate such potential biases, the students were assigned numbers for the study. Also, the grader was not the author. To facilitate this, the test was based on multiple choice answers so that third party grading was feasible. Since the third party is not directly involved in the research, the grading can be assumed to be fair. The answer sheets graded by the grader were not identified as pre-test or post-test.

6.3 Content of the Pilot Curriculum Module

Based on this model for verification and validation, a pilot module was developed to evaluate the concepts and structure of the curriculum outlined in the previous chapter. The test population was the students in the junior-level engineering class taught by Mr. Evans at Bowie High School. Ideally, the entire six week module would have been evaluated. However, we were limited by the constraints discussed below.

Schools are on a busy schedule. Teachers face pressure to complete their existing curriculum within severe time constraints in order to prepare the students for exams. The students are also not available after school hours for validating this curriculum as most are busy with various extracurricular activities. Additionally, an out-of-school evaluation would likely require parental consent.

To address the severe time constraints, the pilot module was designed to fit within a single 45 minute class period and was presented by Mr. Evans. The evaluation consisted of the following tasks:

1. Introduction to the curriculum.

2. Completion of the pre-test survey by the students.
3. Presentation of the sample manufacturing module by the teacher.
4. Demonstration of the hands-on activity
5. Completion of the post-test survey by the students.

The content of the lesson covered introductory concepts in manufacturing, including conventional manufacturing techniques, a comparison of additive and subtractive manufacturing, and a description of the lathe. Details are shown in Appendix B. The module attempts to relate manufacturing with real examples relevant to the students, such as iPhones, bowling pins, Harry Potter's magic wand, and drumsticks.

To avoid the problems associated with obtaining parental consent, the students themselves did not complete the capstone activity. Instead, the activity was presented as a demonstration to the class. While not as effective as direct participation, this approach allowed us to assess their engagement and depth of knowledge quantitatively based on a pre-test/post-test evaluation.

6.4 The Pre-Test and Post-Test Questions

As discussed earlier the format of the pre-test/post-test was objective multiple choice. The test consisted of 10 questions ranging in difficulty from easy to intermediate to expert. There was slightly more emphasis on the intermediate level. Options such as "None of the above" and " All of these" were provided as distractors intended to foster higher order thinking skills in students.[11] The complete instrument is shown below.

Table 8: Questionnaire designed for the Pre-Test and Post-test

The questions are in multiple-choice format and may have more than one correct answer. They are based on the fundamentals of lathes and manufacturing. You have up to 10 minutes to complete the survey.
1. The lathe is a machine tool used for ________ the metal. a. Shaping b. Threading c. Facing d. All of these 2. The cutting tool is ________ in the lathe. a. Stationary b. Dynamic (Moving) c. Not necessary d. All of the above 3. The work piece is held in the _______ a. Chuck b. Tail stock

c. Carriage
d. Head Stock

4. The lathe center is used for _______

a. Cutting
b. Supporting
c. All of these
d. Holding

5. During facing the tool must be moved ________ to the work piece.

a. Parallel
b. Perpendicular
c. At an angle
d. None of the above

6. The drill used in the demo lathe must be at the following speed setting during its operation.

a. High Speed
b. Low Speed
c. Hammer Drill
d. Medium Speed.

7. During the operation of a lathe, do not use ________________ .

a. Glasses
b. Bracelet
c. Safety Gloves
d. Watch

8. A ___________ must be used to tighten the work piece.

a. Safety Key
b. Chuck Key
c. Slot Key
d. None of the above

9. The work piece rotates ________ with respect to the axis of the drill in the demo lathe.

a. Clockwise
b. Counterclockwise
c. Both

10. The demo lathe has a compartment in the center. Its purpose is to

a. Store the waste
b. Store the dust filings
c. Store the tools
d. For aesthetic use. No Specific Functionality.

6.5 Results & Discussion

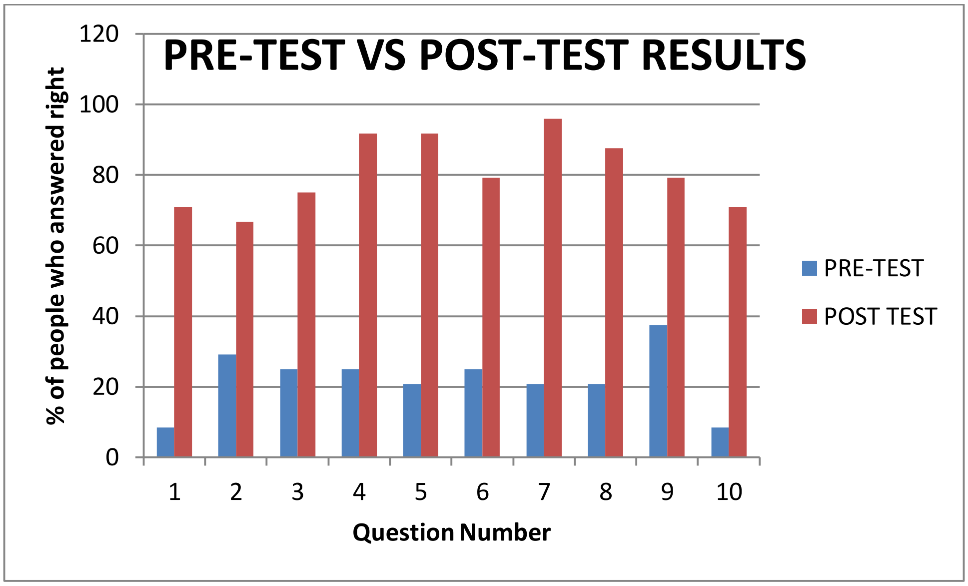

Figure 8: Percentage of correct responses in pre-test (blue) and post-test (red)

Figure 8 highlights the results from the pre-test and post-test. The sample size was 24 students. The average scores for the Pre-Test and Post-Test are also shown in Figure 9. For the pre-test, an average of only 22.1% of the students got an answer right. However, after the sample module was presented, an average of 80.3% answered correctly. This verifies our hypothesis that the students' understanding of manufacturing is increased as compared to before the module. For questions 4, 5, and 7, the percentages of correct answers were 91.7%, 91.7% and 95.0%. The corresponding pre-test percentages were 20.8%, 25.0% and 20.8%, respectively. The data for the evaluation are tabulated below.

Table 9: Cumulative average for the individual questions in the Pre-Test and Post-Test

Question number	Pre-Test (% of class that answered correct)	Post-Test (% of class that answered correct)
1	8.33	70.83
2	29.17	66.67
3	25	75
4	25	91.67
5	20.83	91.67
6	25	79.17
7	20.83	95.83
8	20.83	87.5
9	37.5	79.17
10	8.33	70.83
Average	**22.082**	**80.83**

The students performed best on questions dealing with safety, the lathe center and facing operations. One explanation for these results is that, since these concepts were during the live demonstration, the students had a firm grasp of the concepts. It is also interesting to observe how the students performed with difficult questions requiring higher order thinking skills. The options for these questions were not straightforward and were designed to trick the student. An example is the question on whether the tool was stationary or dynamic with respect to the lathe. The answer can be either as it depends on the perception of the operation. For facing, the tool is stationary with only vertical depth given as feed. For turning, the tool is dynamic but does not have perpendicular motion. The right option for this question is “Not necessary”. About 66.7% of the students answered this correctly on the post-test, an improvement from 29.2% on the pre-test.

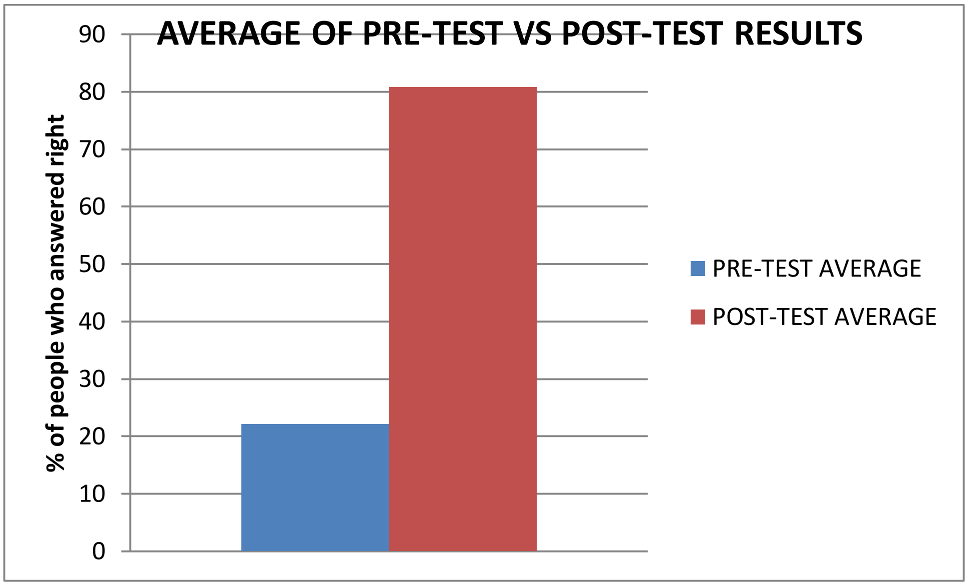

Figure 9: Average of pre-test (blue) and post-test (red) results

CHAPTER 7: Conclusion and Future Work

7.1 Conclusion

Our hypothesis was that the completed module would increase students' understanding of manufacturing. The literature provided an understanding of the challenges faced by current curricula that cater to manufacturing and helped me think of solutions to cater to them. The visits to Bowie High School and Anderson High School in Austin, TX, further deepened my understanding in the area of teaching manufacturing to high school students. I could see clearly see that finance served as a constraint in making manufacturing accessible to high school students, as a huge amount of capital is needed to set up a manufacturing facility. With the goal focused on low cost, the manufacturing curriculum was developed. Several manufacturing curricula currently in existence were studied to understand their strengths and weaknesses, and to better address these. The successful strategies discovered in the research were emulated and implemented into our curriculum. The "Understanding by Design" approach was followed for the curriculum development, keeping the end goals of the student in mind. The course I had previously taken on "Knowing and Learning" from Dr. Empson, helped me to think from the perspective of the high school student. This was vital for the design of the tasks for the curriculum. As a Teaching Assistant for the Senior Design Laboratory under Dr. Crawford, I understood how imperative the capstone project was. This was implemented in our curriculum, thus giving the high school students a taste of what college students do. All of these aspects provided for the development of a very strong curriculum. All that was left for the curriculum was validation. Using a standard approach, the curriculum was validated using the Pre-Test and Post-Test approach. With some constraints, it was decided to validate the curriculum at Bowie High School. Having validated the test results from a pilot study at Bowie High School, it can be concluded that the students gained deeper insight into manufacturing from the sample module as compared with any prior knowledge they had on manufacturing. This evaluation provides evidence to support the hypothesis. Furthermore, an interview with the teacher at Bowie High School provided evidence that a six-week module was easy to plug into the existing curriculum and did not require access to any state-of-the-art machinery, which served as a limitation previously. However, a more complete evaluation is necessary to understand the effectiveness of the entire curriculum.

7.2 Future work

The first step in continuing this work is to test the pilot module with a larger sample size. A sample of 24 students was tested with Bowie High School as the pilot school. This represents a very small portion of the available student population in Austin, let alone the entire country. The module should be evaluated across different demographics based on location, gender and age group.

Next, the entire curriculum needs to be fully developed and evaluated. As different lessons in the curriculum are developed, each can be evaluated and modified as necessary. This process will not only improve developed lessons, but will provide guidance on creating other lessons.

The capstone project is another area where significant feedback is needed. The first step is to pilot the entire activity with a group of students, with particular focus on the degree of difficulty of the activity for the students. This evaluation will also provide a benchmark for the time required to complete the activity. The mini-lathe project was also made very simple to facilitate the students' engagement and involvement while not requiring extensive training in construction skills. However, for schools with appropriate facilities, training and access to these construction tools would provide the students with skills and experience in manufacturing beyond that provided by the base curriculum.

The current six week curriculum does not include field trips to manufacturing sites due to differences in availability of such sites among high schools. Obviously, the addition of field trips would greatly enhance the curriculum and the students' understanding of real world manufacturing. A post-survey conducted after such a field trip would provide insights on the benefits to students.

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APPENDIX A: Principles of Manufacturing Curriculum Outline from Project Lead the Way[15]

UNIT 1: Principles of Manufacturing:

This unit has three lessons spread out over a period of 32 days.

Lesson 1.1: History of Manufacturing

1. Gives a general overview on the history of manufacturing. It explains what manufacturing is and the different stages involved, such as product design, planning, producing, materials control, quality assurance, management, and marketing of that product.
2. Interconnects manufacturing with the economy and the jobs created by it.
3. Addresses health risks and how they can be avoided.
4. Discusses the careers that manufacturing could provide.
5. Describes the various procedures that are used during the creation of products.

Lesson 1.2: Control Systems (10 days)

1. Shows how the technique of drawing flowcharts is used industrywide by technicians, computer programmers, engineers, and professionals in multiple roles and responsibilities.
2. The uses of flowchart in planning depicting the process flow for an entire system and subsystem are shown.
3. The use of flow chart symbols to graphically organize the flow of program control that includes all inputs, outputs and conditions is discussed.
4. Examples of common everyday objects that use control systems to manage the operation are shown.

Lesson 1.3: The Cost of Manufacturing (14 days)

1. Addresses the importance of cost and safety to be considered when designing a control system.
2. The various factors that need to be considered while designing the cost of a product are detailed.
3. The pros and cons of hiring highly skilled or experienced workers must be analyzed in order to keep the costs down.

4. A part that has been manufactured in the least time, has the potential to make the maximum profit.
5. Investments that are geared towards the long term may involve upfront costs but may provide additional savings in the future.

UNIT 2: Manufacturing Processes (Time: 54 days)

This unit has three lessons spread out over a period of 54 days.

Lesson 2.1: Designing for Manufacturability (10 days)

1. Explains what design is and how it can be used to systematically solve problems.
2. Discusses the different considerations for manufacturing a quality part.
3. Lists the material properties that must be considered during the design process.
4. Discusses the ethical responsibility of manufacturers to provide safety information about the product to the consumer.
5. Describes the legal responsibility of manufacturers to provide safety information about the product to the consumer
6. The code of conduct and the code of ethics that members of different engineering disciplines are expected to follow are discussed.
7. The study of previous engineering failures could help avoid future failures.

Lesson 2.2: How We Make Things (6 days)

1. Defines prototyping and describes its purpose in the design process.
2. Addresses the need to process a raw material before it can be used for manufacturing.
3. Explains one of the oldest processes used in manufacturing, the separating process.
4. Discusses subtractive processes such as milling and shearing to create products.
5. Explains the use of latest technologies such as ECM, EDM, laser and water cutting for improving accuracy and increasing the efficiency of material removal rate.
6. Discusses the common types of materials that are well-suited for manufacturing, such as metals, plastics and ceramics.
7. The material properties of a product play a key role in the selection of the manufacturing process for the product.

Lesson 2.3: Product Development (38 days)

1. Manufacturing processes can be performed by a variety of machines.
2. Communication to the machine occurs via machine code.
3. Consistency and quality control are maintained via the use of jigs and fixtures.

4. Computer Aided Design (CAD) programs make use of Computer Aided Manufacturing (CAM) tools to make physical models.
5. The continuous advancement in machines and technology has greatly influenced the way products are manufactured today.
6. There are several variables and parameters in machining operations which affect the end product in manufacturing.
7. Any manufacturing firm needs a profit margin from a product for its survival.
8. Prototyping processes have been improved over the years and play a key role in the design cycle of manufactured goods.

Unit 3: Elements of Automation (46 days)

Lesson 3.1: Introduction to Automation (19 Days)

1. Automation has evolved and has been influenced by many factors.
2. There are various careers in automation.
3. Various types of robots speed up and improve the production of manufactured goods.
4. Robots have an edge over humans in certain scenarios, such as hazardeous working conditions, monotonous motions, or long hours of work.
5. The process called handshaking enables machines and robots communicate with each other.

Lesson 3.2: Elements of Power (10 Days)

1. Power is produced in several ways and is transmitted in various forms, such as electrical, pneumatic, hydraulic, and mechanical motion.
2. Fluid power is inversely proportional to the area upon which the force is being applied.
3. Feedback in the control systems and products is provided by sensors.
4. There are several forms of fluid power, of which pneumatics is commonly preferred and can be used to operate machines.

Lesson 3.3: Robotic Programming and Usage (17 Days)

1. Certain basics must be learned in programming, such as variable declaration, loops and debugging.
2. The manufacturing industry employs a variety of robots and programming languages that are unique.
3. Most common products are made by employing microcontrollers.

4. Robots perform diverse functions in diverse environments.
5. Parameters such as payload and work envelope, which depend on the type of the task, determine the size of the robot.

Unit 4: Integration of Manufacturing Elements (Time: 47 Days)

Lesson 4.1: Integration of Manufacturing Elements (10 Days)

1. Mass production is a key concept for products that are created using the same set of steps.
2. A group of machines that perform similar operations together is called a workcell.
3. A system that can be adapted to manufacture various products is called a flexible manufacturing system.
4. When a system is preferred over another, certain tradeoffs can be made.
5. Process flow design is an important process that impacts the overall production time and profit of the product.
6. The design and development process uses flowcharting to plan and depict the detailed process flow for an entire system and all of its subsystems.
7. The different phases of the product development process are illustrated using flowcharting.
8. Manufacturing and automation careers vary by scope and location.

Lesson 4.2: Manufacturing Application (37 Days)

1. Process flow design impacts the overall production time and product profit substantially.
2. During the design and development process, flowcharting is used to plan and depict the detailed process flow for an entire system as well as all of its subsystems.
3. The overall phases of the product development process can be illustrated via flowcharting.
4. Serious injury can be avoided by addressing safe operating procedures in a Computer Integrated Manufacturing environment.
5. Efficiency and cost are important parameters to be considered when choosing a manufacturing system.
6. Appropriate sensors aid an engineer in various processes in manufacturing to ensure high quality part production.
7. Automated operation in the factory must have proper sequencing.

8. Prior identification of the electrical and fluid power systems is required, to complete the desired manufacturing system.

From the above course outline we see that, although it covers a wide range of concepts on manufacturing in detail, it does not give much information about the various types of manufacturing processes. It does introduce the students to Computer Integrated Manufacturing programming and gives them a concrete foundation on such concepts as dimensioning, tolerances, materials, automation, cost, flowcharting, prototyping and accuracy. These are important concepts that could for the curriculum developed in this research. Alternatively, the curriculum does not expose the difference between additive and subtractive manufacturing processes; discuss when one process is preferred over another, or the methods and tools employed to choose a manufacturing process; present the different classifications of subtractive manufacturing or additive manufacturing; describe the different parameters that affect each manufacturing process. These potential shortcomings were addressed in the curriculum we developed.

APPENDIX B: Class Presentation at Bowie High School

Outline :

- What is Manufacturing
- Types of Manufacturing
- Uses of Manufacturing in our everyday lives.
- What is a lathe ?
- How does it work ?
- Show time ! – Live working of the machine.

WHAT IS MANUFACTURING ?

Definition : Make (something) on a large scale using machinery.

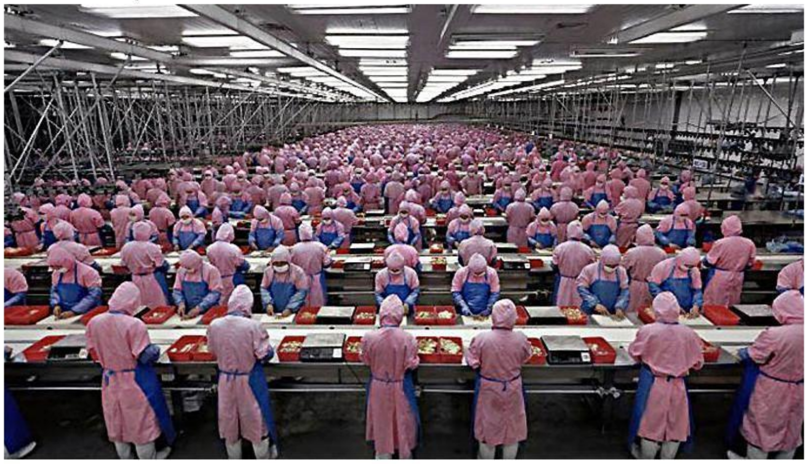


Figure 1 : Iphone Manufacturing Facility in China[1]

Manufacturing is Omnipresent !

Table[2]

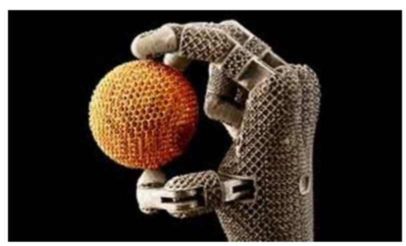
Can[3]

Iphone [4]

Mug [5]

Types of Manufacturing.

1. Subtractive Manufacturing[6]

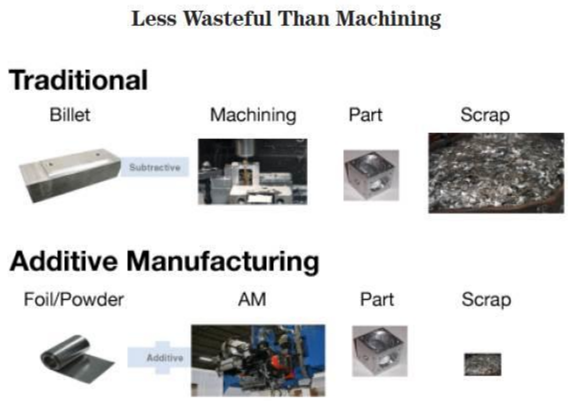


2. Additive Manufacturing[7]

3. Forming[8]

Subtractive Manufacturing vs Additive Manufacturing

- Material is removed as waste during the process of mach



Picture summing difference Additive Vs Subtractive Manufacturing[9]

What is a Lathe ?

A **lathe** /ˈleɪð/ is a machine tool which rotates the workpiece on its axis to perform various operations such as cutting, sanding, knurling, drilling, or deformation, facing, turning, with tools that are applied to the workpiece to create an object which has symmetry about an axis of rotation.

Picture of a Lathe[10]

Primary functions of a Lathe

Turning is an operation that reduces the diameter. [11]

Facing is an operation that reduces the length of the workpiece. [12]

Parts of a Lathe

Parts of a Lathe [13]

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3. http://talksense.weebly.com/uploads/3/0/7/0/3070350/3131890.jpg
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APPENDIX C: Link to the Instructions for Lathe Construction

The link to the video containing the construction, assembly and testing of the 'Make and Take Lathe kit' is:

https://www.youtube.com/watch?v=5DIhQN4MLMk&feature=youtu.be

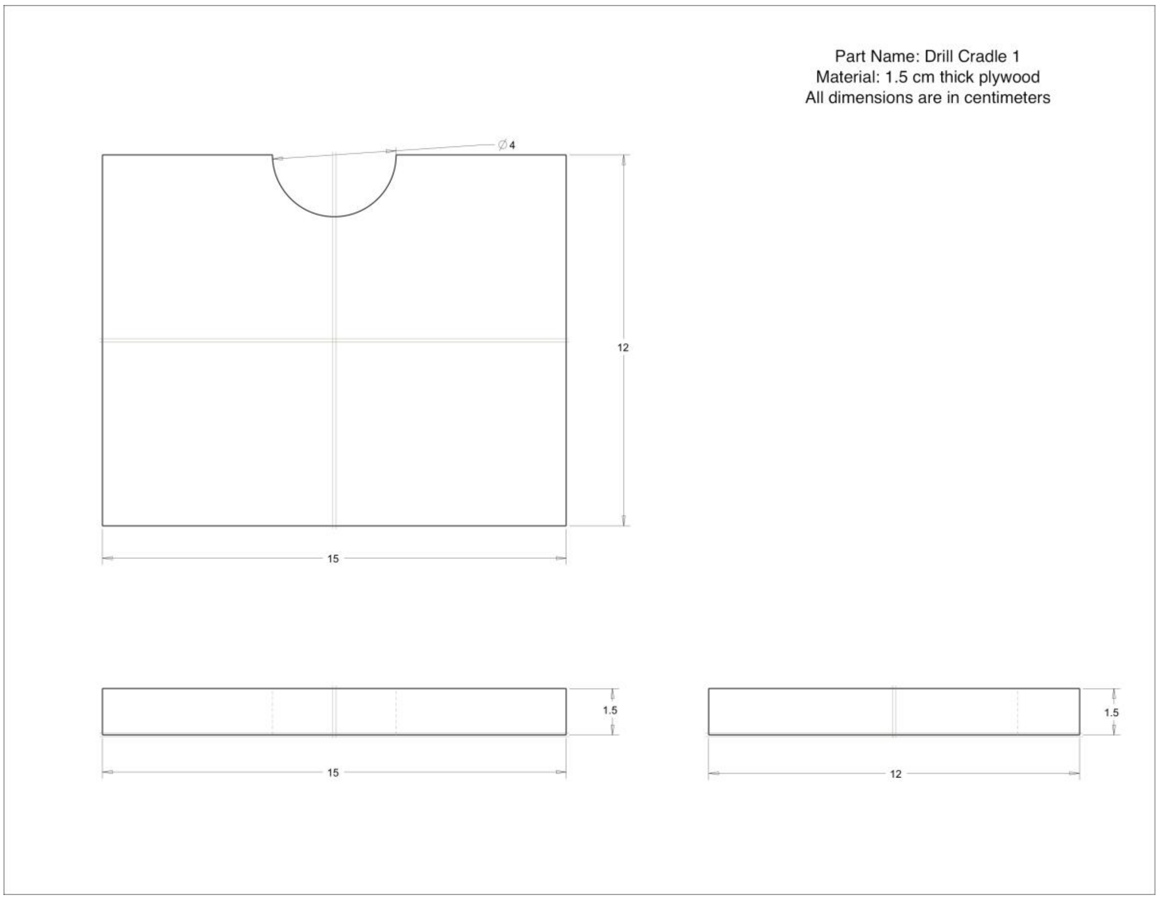
The video is titled "Lathe Instructables Final Video".

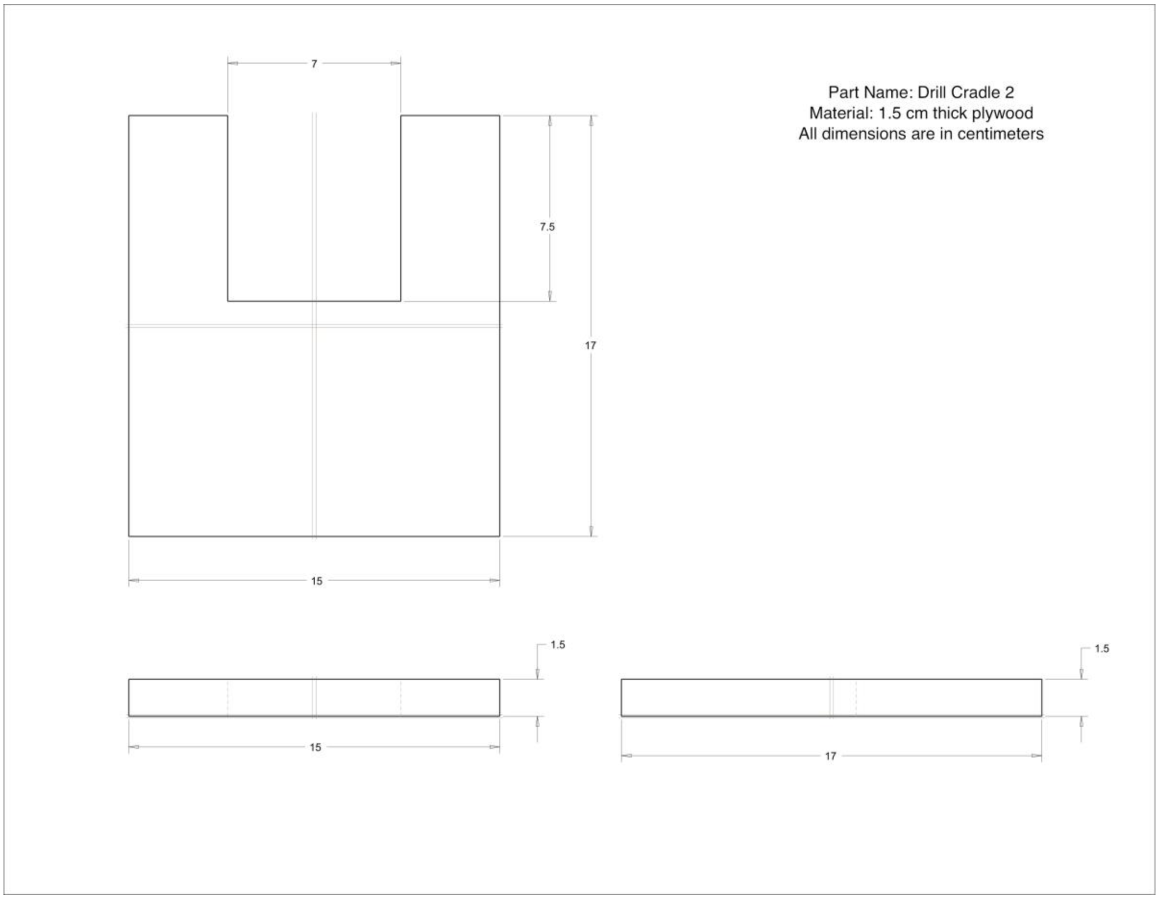
APPENDIX D: Dimensioned Drawings and Bill of Materials for Mini-Lathe

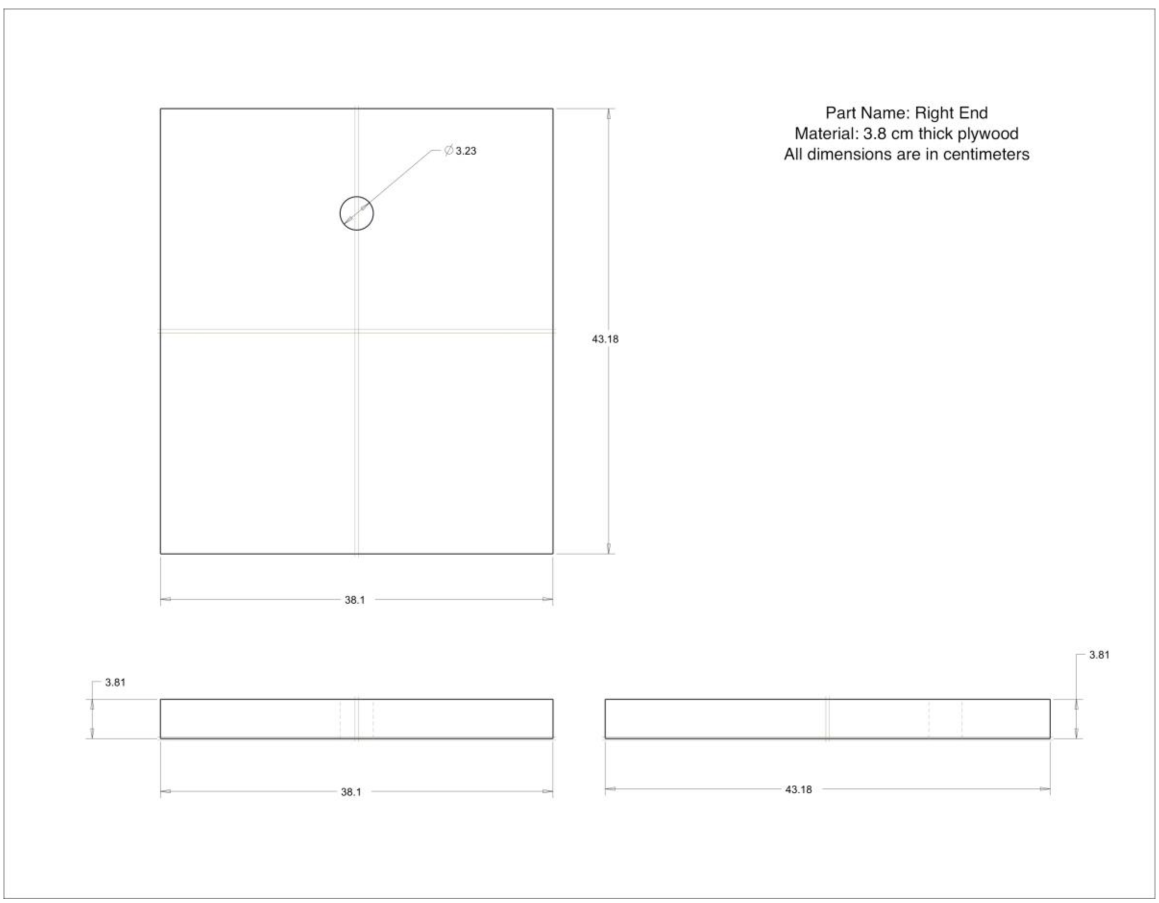
Bill of Materials for Desktop Lathe

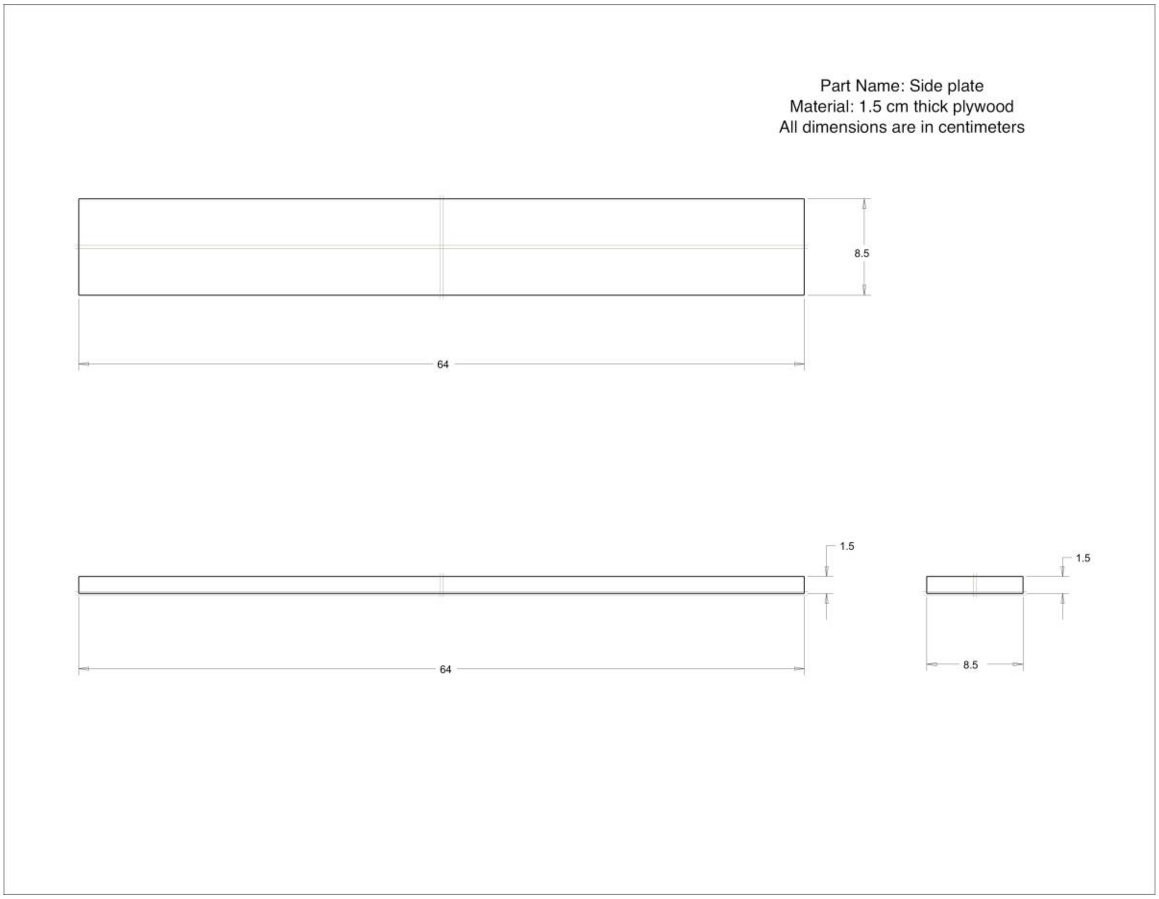
Part Number	Part Name	Quantity	Material
1	Drill Cradle 1	1	1.5 cm thick Plywood
2	Drill Cradle 2	1	1.5 cm thick Plywood
3	Right end	1	3.8 cm thick Plywood
4	Side plate	2	1.5 cm thick Plywood
5	Base	1	1.5 cm thick Plywood
5	2" Deck Screw	15	Steel

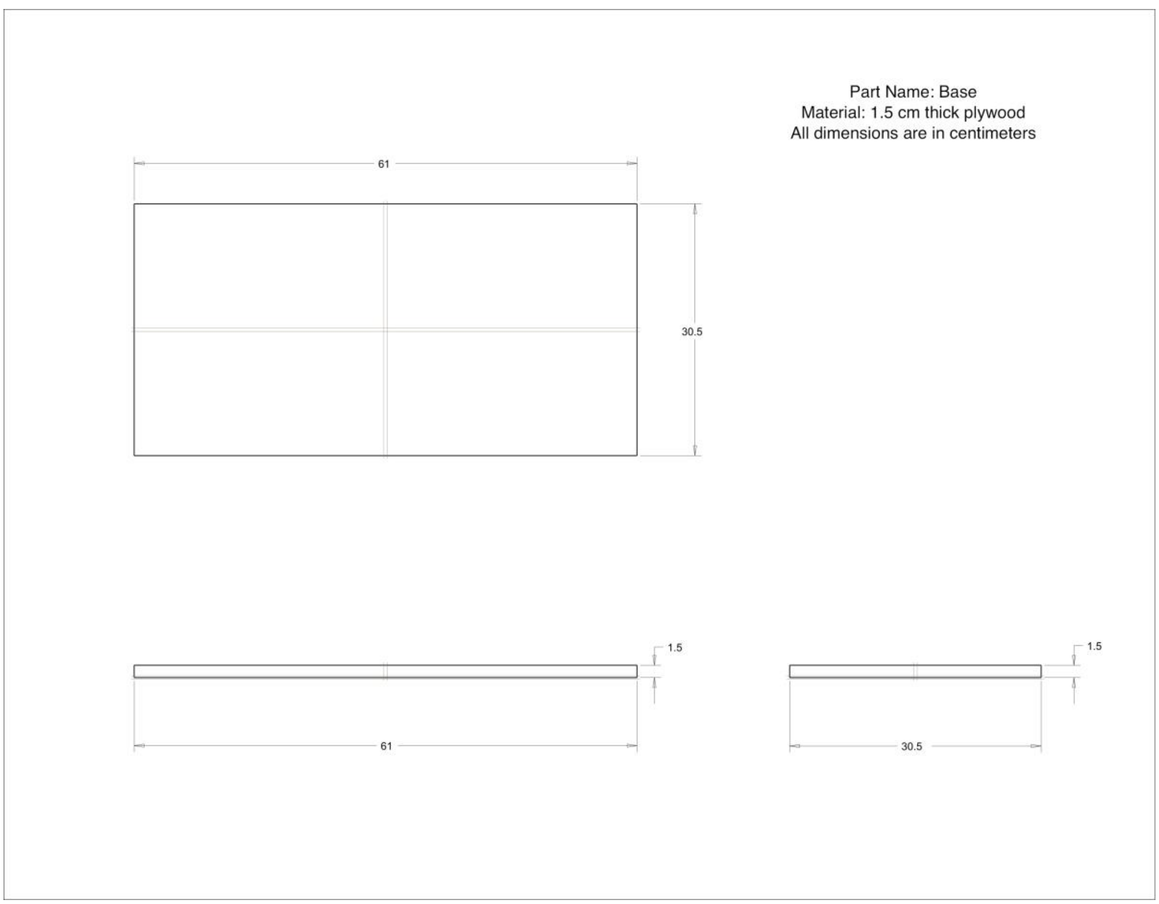
Dimensioned Drawings of the Plywood Parts




Part Name: Drill Cradle 2
Material: 1.5 cm thick plywood
All dimensions are in centimeters
7
7.5
17
15
1.5
15
1.5
17


Part Name: Right End
Material: 3.8 cm thick plywood
All dimensions are in centimeters
∅ 3.23
43.18
38.1
3.81
38.1
3.81
43.18


Part Name: Side plate
Material: 1.5 cm thick plywood
All dimensions are in centimeters
8.5
64
1.5
1.5
64
8.5


Part Name: Base
Material: 1.5 cm thick plywood
All dimensions are in centimeters
61
30.5
1.5
1.5
61
30.5