Glendale Unified School District

High School

February 7, 2023

Department	Career & Technical Education
Course Title	Intermediate Manufacturing (Formerly Computer Aided Manufacturing 5-6)
Course Code:	5436V/5437V
Grade Level:	9-12
School(s) Course Offered:	Clark Magnet High School
UC/CSU Approved	Yes, "G" Electives
Recommended Prerequisite	None
Recommended Textbooks:	CNC Machining for Engineers & Makers by Charles Davis ISBN-13: 978-0-615-99935-7 , 2014, NexGenCAM, Inc. Haas VF / HS Series CNC Machine Programming Workbook, Haas Automation, Inc., 2006 Learn CNC for Haas, Immerse Engineering, Inc., v.16/2016, www.immerse2learn.com
Course Content:	Students will gain proficiency in the setup, programming, and operation of computer numerically controlled (CNC) manufacturing equipment, with an emphasis on the Haas control system. Students will learn foundational skills necessary for manufacturing such as machine shop safety, applied mathematics, precision measurements, calculation of feeds and speeds, and print reading. After learning the fundamentals, students will learn and practice machine setup and operation using both virtual and

real CNC machines as they work toward earning industry-recognized certification. Students will become proficient in the G and M code program commands and cycles used to operate the machines by hand-programming a part from a provided drawing print. Students will then setup and operate the machine to produce the finished part from raw material, using the program code they developed. During second-semester, students will use advanced Computer-Aided Manufacturing (CAM) software to program 2.5D and 3D high-speed machining toolpath strategies using solid model geometry. Students will run 3D simulations of the machining process to check for proper machining technique and to verify proper part outcomes. Students will then optimize the cutting strategies for efficiency in production, and produce tangible products from raw materials.

Unit 1: Machine Shop Safety (2 weeks)

STANDARDS
4.0 Technology, 5.0 Problem Solving and Critical Thinking, 6.0 Health and Safety, 7.0 Responsibility and Flexibility, 9.0 Leadership and Teamwork
Machining and Forming Technologies Pathway Standard 5.0, 6.0, 7.0, 8.0, 9.0, 11.0

A. In this unit, general lab safety is covered as well as personal protective equipment and safety precautions before, during, and after the machining process. General lab safety instruction includes lessons about evacuation routes and procedures, maintaining a clean and orderly workspace, use of compressed air, and locations of first-aid kits and fire extinguishers. The lesson on personal protective equipment discusses eye and ear protection, proper work attire, respiratory protection, and entanglement hazards. After the general safety and personal protective equipment lessons, students are taught safety practices used before machining. These practices involve becoming familiar with safety mechanisms, controls, and guards related to specific machine tools, handling raw materials, securing work pieces, and inspecting the condition of tools prior to beginning work. Students then learn about safety precautions during machining such as avoiding distractions, maintaining one operator in control, and keeping hands away from machines that are powered on. Finally, the unit finishes with instruction on post-machining safety procedures such as removing chips, cleaning the work area, and powering down the machine. All students must pass a safety test before being allowed to work in the lab. Incorrect answers are re-evaluated and analyzed to clear any points of confusion or misunderstanding among students, to ensure the safety of everyone in the lab.

B. Students are frequently presented with quizzes and test questions. The questions are typically true/false, multiple choice, or multiple selection in nature and often include written questions as well as visual diagrams.

Unit 2: Foundational Mathematics (4 weeks)

STANDARDS
4.0 Technology, 5.0 Problem Solving and Critical Thinking, 6.0 Health and Safety, 7.0 Responsibility and Flexibility, 9.0 Leadership and Teamwork
Machining and Forming Technologies Pathway Standard 5.0, 6.0, 7.0, 8.0, 9.0, 11.0

A. The foundational mathematics unit includes numerous lessons and exercises on mathematical concepts and techniques necessary for performing measurements and estimations and for performing calculations in a manufacturing environment in general. It was found through observation that even students in higher level math classes such as Calculus often lack a firm grasp on simpler concepts when taken out of context and put to use in practical scenarios. For that reason, the unit begins with instruction on the basic skills of rounding decimal numbers and arithmetic order of operations. Students then practice performing arithmetic operations on fractional numbers. Although students have already learned these low-level skills in prior math classes, the review reinforces a strong understanding and builds student confidence to a point where these simple mathematical operations can be applied quickly and mentally in a manufacturing environment, without the need to refer to a textbook or notes. After learning fractions, the students learn how to perform conversions for angle measures between angles expressed in decimal degrees and angles expressed as degree, minute, second measures. Finally, students learn and practice conversion between distance measurements in the inch and metric systems.

B. Students are frequently presented with quizzes and test questions. The questions are typically true/false, multiple choice, or multiple selection in nature and often include written questions as well as visual diagrams.

Unit 3: Applied Geometry and Trigonometry (4 weeks)

STANDARDS
4.0 Technology, 5.0 Problem Solving and Critical Thinking, 6.0 Health and Safety, 7.0 Responsibility and Flexibility, 9.0 Leadership and Teamwork
Machining and Forming Technologies Pathway Standard 5.0, 6.0, 7.0, 8.0, 9.0, 11.0

A. The applied geometry and trigonometry unit provides students a solid foundation of mathematical knowledge necessary for interpreting engineering drawings. The unit begins with instruction on geometric concepts of parallel, perpendicular, and bisecting lines, and then moves to defining polygons and calculating perimeter, and then defining circles and calculating circumference, diameter, and radius. The unit then shifts focus into angles where students learn the meaning of complementary and supplementary angles and how to convert angle measurements between degree and radian measures. After learning about angles, students then proceed to learn about triangles where they identify right, equilateral, and isosceles triangles and apply the Pythagorean Theorem to find unknown lengths of right triangle sides. The unit concludes with a lesson on simple trigonometry of angles and right triangles. Students learn the meaning of sine, cosine, and tangent functions and apply these functions and the inverse of these functions to solve for unknown lengths and angles in right triangles. Finally, students learn about the unit circle, and how to recognize standard position angles, and how to find the coordinates of points along the unit circle which occur at standard position angles. By building knowledge and skills in geometry and trigonometry, students are better prepared to interpret engineering drawings and perform calculations needed to find unknown dimensions, locations, or measurements.

B. Students are frequently presented with quizzes and test questions. The questions are typically true/false, multiple choice, or multiple selection in nature and often include written questions as well as visual diagrams.

Unit 4: Precision Measurements (4 weeks)

STANDARDS
4.0 Technology, 5.0 Problem Solving and Critical Thinking, 6.0 Health and Safety, 7.0 Responsibility and Flexibility, 9.0 Leadership and Teamwork
Machining and Forming Technologies Pathway Standard 5.0, 6.0, 7.0, 8.0, 9.0, 11.0

A. The precision measurements unit includes instructional lessons and hands-on practice on the three primary types of measuring instruments used in the manufacturing of fabricated metal products: the steel rule, the slide caliper, and the micrometer. The selection of measuring device based upon the degree of precision needed is discussed. The unit begins with instruction on proper care, handling, cleaning, and storage of measuring instruments. Students then learn how to accurately measure using steel rules with various styles of graduations down to one hundredth of an inch on a decimal scale, and to one sixty-fourth of an inch on a fractional scale. Additionally, metric steel rules are covered and students practice making accurate measurements down to the nearest one millimeter. Students learn the difference between major and minor increments on the steel rule and apply their knowledge of fractions from Unit 2 to performing simple addition and subtraction of minor increments to and from major increments while measuring. Students then learn and practice how to read the three types of slide calipers including vernier, dial, and digital types. Students learn how to read a fractional inch vernier caliper to the nearest one-hundred-twenty-eighth of an inch and how to read a decimal inch vernier caliper to the nearest one-thousandth of an inch. Finally, students learn how to read a metric vernier caliper to the nearest five hundredths of a millimeter. Students are then taught how to read a dial caliper and a digital caliper to the nearest one thousandth of an inch. Across all types of calipers, students are taught how to make internal, external, depth, and height measurements and compare measurements between each other and between different types of calipers to ensure proper reading technique. For more precise measurements, students learn how to use three types of micrometers: external, internal, and depth. Students learn how to verify the calibration of each type of micrometer and practice careful handling and operation while making precision measurements to the nearest five ten-thousandths of an inch.

B. Students are frequently presented with quizzes and test questions. The questions are typically true/false, multiple choice, or multiple selection in nature and often include written questions as well as visual diagrams. Measuring activity: Students are each given a unique machined component and are asked to perform various measurements such as length, thickness, and diameter on different geometric features of the component. The measurements are performed using all types of measuring tools as applicable: steel rules, vernier, dial, and digital calipers, and internal, external, and depth micrometers. Students record their measurements to a page. Each student then exchanges their component with one given to a different student, and performs the activity again, independently taking measurements of a different component. At this juncture, each component has undergone two independently-taken sets of measurements, with each set containing measurements taken by a variety of measuring devices. The students compare notes with each other, and clear up any points of discrepancy or confusion by demonstrating the technique used to measure and to read the measurement, and validating their procedure with the instructor.

Unit 5: Engineering Drawing Interpretation (4 weeks)

STANDARDS
4.0 Technology, 5.0 Problem Solving and Critical Thinking, 6.0 Health and Safety, 7.0 Responsibility and Flexibility, 9.0 Leadership and Teamwork
Machining and Forming Technologies Pathway Standard 5.0, 6.0, 7.0, 8.0, 9.0, 11.0

A. In this unit, students learn how to interpret engineering drawings and the role they play in manufacturing both in conjunction with and aside from digital solid model data. The unit begins with an overview of ANSI and ISO as two different standards organizations, each with fundamentally different standards for presenting model data views in an engineering drawing. Placement of orthographic views on the drawing sheet and determination of drawing scale is covered and the differences between first-angle and third-angle projection are discussed. Students also learn how to read and interpret other drawing attributes such as the title block, notes, callouts, and line styles. The unit then teaches different methods of dimensioning including location and datum dimensioning and where each is applicable. Finally, tolerancing is discussed in concept, style, and interpretation. The necessity for tolerancing is demonstrated, and the concepts of tolerance zone and tolerance accumulation as a result of dimensioning style are covered. Students learn classical unilateral, bilateral, and block tolerancing styles and learn a basic introduction to geometric dimensioning and tolerancing as defined by the ASME Y14.5-2009 standard. Finally, students learn how tolerance can affect the fitment of mating pieces and why tolerance must be considered to prevent ambiguous fitment when either a clearance fit or interference fit is desired

B. Students are frequently presented with quizzes and test questions. The questions are typically true/false, multiple choice, or multiple selection in nature and often include written questions as well as visual diagrams. Orthographic view drawing: Students are provided a tangible three-dimensional model of an object featuring multiple surfaces, edges, steps, and holes. The students then determine which orientation to classify as the "front" view, and proceed to sketch it by hand along with the other five orthographic projections. Students sketch the projected views following both ANSI third-angle and ISO first-angle standards. The drawings are checked for accuracy in relative scale and for proper representation of the part using geometry lines and hidden lines. The forward approach to drawing creation beginning with the 3D model assists students in developing the spatial skills needed to visualize a 3D component from its representation as 2D views when following the reverse approach of interpreting provided engineering drawings in later coursework.

Unit 6: CNC Tools and Speed and Feed Calculation (4 weeks)

STANDARDS
4.0 Technology, 5.0 Problem Solving and Critical Thinking, 6.0 Health and Safety, 7.0 Responsibility and Flexibility, 9.0 Leadership and Teamwork
Machining and Forming Technologies Pathway Standard 5.0, 6.0, 7.0, 8.0, 9.0, 11.0

A. This unit begins with an overview of the various types of commonly-used tools found in CNC machining such as end mills, drills, taps, and corner rounding tools. Types of tool materials such as carbide and high-speed steel are discussed as well as tool geometry including the number of cutting flutes. The theory of chip formation in the cutting process is briefly discussed, to the extent necessary to understand how chip load is affected by other cutting parameters such as feed and speed. Common cutting speeds measured in units of surface feet per minute for various materials are presented, and students build an understanding of how and why cutting speeds are driven by material properties. Students learn and practice using the mathematical equations for calculating speed and feed rate in both milling and turning operations. Finally, students learn how to calculate tapping operation feed rates based upon spindle speed and thread pitch.

B. Students are frequently presented with quizzes and test questions. The questions are typically true/false, multiple choice, or multiple selection in nature and often include written questions as well as visual diagrams.

Unit 7: 3-Axis CNC Milling Machine Setup and Operation (4 weeks)

STANDARDS
4.0 Technology, 5.0 Problem Solving and Critical Thinking, 6.0 Health and Safety
7.0 Responsibility and Flexibility, 9.0 Leadership and Teamwork
Machining and Forming Technologies Pathway Standard 5.0, 6.0, 7.0, 8.0, 9.0, 11.0

A. In this unit, students learn how to safely and effectively setup and operate a Haas CNC mill in depth. The unit begins with an overview of machine kinematics including definition and direction of the three axes of motion. Students then learn about the nine organizational groupings of keys on the Haas control panel and how each is effectively used in the setup and operation of the machine, and take an in depth look at the operational modes such as edit, memory, and handle jog. Students learn and demonstrate pre-startup procedures such as checking coolant, oil, grease, and air pressure levels, perform the machine powerup and reset procedure, and initiate a spindle warmup program. After learning about the control panel and how to power on the machine, students practice basic manual operations such as loading, changing, and unloading tools, and handle jogging the machine in each of the three axes. Once proficiency is gained in manual operations, students then learn how to perform a work setup procedure including loading a workpiece to a mill vise, setting tool length offsets using a Z axis dial indicator, and setting the part work coordinate origin in the XY plane by using an edgefinder. After the workpiece is setup and offsets are determined, students use machine control's editor to insert and alter G and M program codes both from a manuscript as well as from an external data storage device, and demonstrate how to simulate a program in graphics mode on the control. After the graphics simulation is successfully run and verified, students run a program on a machine line by line, verifying coordinates and proper operation throughout while utilizing speed, feed, and rapid motion overrides and feed holds during the process.

B. Student Skills Assessment Checklist: Through the skills assessment checklist, students demonstrate their practical knowledge and skills while operating the CNC milling machine. When students are ready to demonstrate their skills, the instructor joins him or her standing at the CNC milling machine in the lab for a one-on-one interview and assessment of skills. The interview and skills assessment typically takes place over four class sessions spanning over a period of approximately three weeks. Eight primary modules from Unit 7 are addressed on the checklist: machine motion, control panel layout and organization, machine start-up procedure, basic manual operations, edit capabilities, program entry, and program run. Each of the eight aforementioned modules includes multiple proficiency check items, totaling 35 discrete machine setup and operation proficiencies in all. Each proficiency check prompt is given to the student verbally during the interview and assessment, and the student is not allowed the use of any notes or references during the assessment. Students must pass every proficiency item to a satisfactory level to earn the industry-recognized certification for this unit. A passing mark indicates that the student has demonstrated confidence with the information they communicate or the skill they demonstrate to the instructor.

Unit 8: 3-Axis CNC Milling Machine Programming (4 weeks)

STANDARDS
4.0 Technology, 5.0 Problem Solving and Critical Thinking, 6.0 Health and Safety, 7.0 Responsibility and Flexibility, 9.0 Leadership and Teamwork
Machining and Forming Technologies Pathway Standard 5.0, 6.0, 7.0, 8.0, 9.0, 11.0

A. In the milling machine programming unit, students learn the fundamental G and M codes used to command the motions and operations of the Computer Numerically Controlled milling machine. A primary curricular aide used during instruction for this unit is the Haas Mill Programming Workbook, in which students both read and write in guided exercises. Students begin with a positioning exercise to check for understanding of Cartesian coordinates and to demonstrate the difference between absolute and incremental positioning techniques. Students then learn the difference between preparatory functions represented as G codes and miscellaneous functions represented as M codes, and are introduced to specific codes frequently used in machine programming. Students learn the differences between modal and non-modal commands, which specific codes fall under each category, and which codes are set by default in the machine control upon startup. Program structure is presented highlighting standard sets of commands used at the beginning and end of each program and operation. Then, students learn the commands for linear and circular interpolation and the syntax of each before completing an exercise in which they write a program to command a cutting tool to follow a drawn part profile with both linear and circular features. Students are also taught how rapid positioning commands differ from interpolation commands in orchestrating the machine’s motion between points in a coordinate plane. After students are familiar with basic positioning commands, the concept and application of cutter compensation is reviewed, and students build an understanding of when, why, and how cutter compensation is used in programming. The unit then transitions into an in-depth study of machine canned cycles, including various cycles for drilling, tapping, and boring operations. Finally, the unit concludes with instruction on G codes used to produce linear and circular bolt hole patterns. Once students are familiar with all the major elements of the CNC mill programming language, they complete a project to hand-code a five-operation program to produce a part specified by a provided engineering drawing. The proficiencies students gain in this unit comprise the industry-recognized certificate in 3-Axis CNC Milling Machine Programming.

B. Manually-written G and M code program: In this assignment, students apply their knowledge of CNC machine programming in the G and M code language by hand-programming a part specified by a printed engineering drawing and produced on the 3-Axis vertical CNC milling machine. Students may use either the machine control or a simple text editor to write the code, but are not allowed to generate the code by any automated CAM software or process. By the time students reach this assignment, they have learned how to interpret drawings and how to program all the relevant G and M codes as well as the types of tooling necessary to produce the part. For these reasons, students are expected to develop the program with absolutely minimal input from the instructor. Students may collaborate with each other to some degree, however their programs must reflect significant individual effort and time spent. The part includes drilled, tapped, and chamfered hole features and a milled slot feature, and requires five tools and operations to produce. The use of canned cycles is required for the drilling and tapping operations at multiple hole locations, and federates are calculated to appropriate values for the tools and material. Development, refinement, and test-running of the program code on a simulator typically occurs over approximately seven 90-minute class periods from start to finish of the assignment. While developing the program code comprises one assignment on its own, setting up and running the program on the machine is a separate assignment detailed in Unit 7 above.

<u>Unit 9: 2.5D Toolpath Strategies</u> (4 weeks)

STANDARDS
4.0 Technology, 5.0 Problem Solving and Critical Thinking
6.0 Health and Safety, 7.0 Responsibility and Flexibility, 9.0 Leadership and Teamwork
Machining and Forming Technologies Pathway Standard 5.0, 6.0, 7.0, 8.0, 9.0, 11.0

A. After completing the programming exercises and project in Unit 8, students have a strong understanding of the commands used to produce different types of part features and geometry, but quickly realize that to program more advanced parts featuring complex contours and pockets would take more program code than is practical to produce by hand programming. Students learn how to use advanced Computer-Aided Manufacturing (CAM) software to import solid model data from a Computer-Aided Design (CAD) program to create advanced toolpaths which are then posted as thousands of lines of G code used to control the machine. First, students learn how to set up the virtual raw material or stock in relation to the solid model and how to choose a coordinate origin for the machining processes. Students learn how to select toolpath cutting strategies based upon part geometry and the types of tools used. In this unit, the parts students program feature vertical walls and are prismatic in nature, with the majority of toolpath motion occurring in two dimensions in the XY plane. Contours, pockets, holes, and islands vary in depth in the Z direction, hence the nomenclature "2.5D." Strategies learned include facing, contouring, chamfering, corner rounding, open and closed pocketing, slotting, drilling, and tapping. The difference between constant-engagement (high speed) toolpaths and traditional toolpaths is emphasized, and students gain an understanding of the shortcomings of traditional toolpaths in producing parts with tight-radius pocket features. For each operation, speeds and feed rates are analyzed in depth using an advanced calculation tool, which builds upon experience gained in Unit 6. Students learn how to adjust cutting parameters such as stepover and depth to maximize material removal rates while ensuring the strength and capabilities of the machine and cutting tool are utilized to their fullest extents, but not exceeded. After optimizing cycle times for efficiency, students gain a sense of understanding that in a production environment, the time it takes to produce a part is directly related to the economics of the company's business model and to the price point of the product sold to a distributor or to the end consumer. Finally, once the part is programmed, verified, and optimized, students produce it from raw materials on the 3-axis CNC milling machine and check for proper outcomes.

B. Prismatic Part CAM Program: In this assignment, students are given a solid CAD model of a prismatic part with a variety of features that can be created using 2.5D machining strategies. Part features include holes, contours, pockets, and chamfers. Students must select and apply the appropriate tooling, toolpath strategies and order of operations to produce the part from raw material of a specified size. Additionally, students must select clearance, plunge, and depth planes for each operation. Within each operation, students must determine and apply the appropriate depths, cutting increments, stepover distances, and toolpath entry and exit styles. Once the operations are programmed using the CAM software, the toolpath is back-plotted to visualize the path of motion of the cutting tool during interpolation feed moves and during rapid moves. The total estimated cycle time is analyzed as well as the cycle time for each machining operation, and speeds and feed rates are optimized using an advanced calculation tool.

Unit 10: 3D Toolpath Strategies (4 weeks)

STANDARDS
4.0 Technology, 5.0 Problem Solving and Critical Thinking, 6.0 Health and Safety
7.0 Responsibility and Flexibility, 9.0 Leadership and Teamwork

Machining and Forming Technologies Pathway Standard 5.0, 6.0, 7.0, 8.0, 9.0, 11.0

A. This unit expands upon the previous by teaching students how to produce advanced toolpath strategies which utilize simultaneous motion of all three axes. Students quickly realize that the variety and detail of parts that can be produced using 3D strategies far surpasses what is possible using 2.5D strategies. First, students are introduced to high speed 3D material roughing strategies and learn how to select key toolpath parameters such as step over and step down. Then, students learn how to apply 3D finishing strategies such as parallel finish and 3D scallop to solid models featuring non-vertical walls and multiple concave and convex radii. The abilities and limitations of cutting tools to produce certain geometric features using various approaches is discussed, and the concepts of tolerance and surface finish quality are presented as factors which are inversely proportional to production time and cost. Students run 3D virtual simulations of the 3D toolpaths and make comparisons between a virtually-machined component and the original solid model to determine what areas may need different or additional finishing strategies applied. The concept of rest-machining is introduced and applied, and the simulation is repeated through multiple iterations until proper results are achieved. Once the part is programmed, verified, and optimized, students produce it from raw materials on the 3-axis CNC milling machine and check for proper outcomes

B. 3D Part CAM Program: The 3D part is machined with adaptive roughing strategies using a flat end mill and a variety of 3D contouring and surfacing strategies using a ball endmill. In this assignment, an emphasis is placed on determining toolpath parameters that result in a reasonable compromise between surface finish quality and part cycle time. Students need to apply different types of finishing toolpaths to areas of different 3D geometry such as conical and spherical surfaces as well as surfaces of uniform cross section whose curve appears in a cross section taken in the XZ or YZ plane.

Unit 11: Manufacturing as a Career (2 weeks)

STANDARDS
4.0 Technology, 5.0 Problem Solving and Critical Thinking, 6.0 Health and Safety
7.0 Responsibility and Flexibility, 9.0 Leadership and Teamwork
Machining and Forming Technologies Pathway Standard 5.0, 6.0, 7.0, 8.0, 9.0, 11.0

A. In this unit, students come to realize that entering a career in manufacturing is not about the grungy repetitive, monotonous work of decades past, but involves highly skilled occupations that take place in very clean, high-tech environments and require a great variety of knowledge and skills to perform successfully. Students also realize that highly skilled individuals in the manufacturing industry can earn wages considerably higher than in many other industries. Students conduct research on various types of manufacturing employers and occupations and report back with their findings. Additionally, students develop a personal resume indicating their skills and certifications gained through the class. Students gain valuable insight into manufacturing as a career either through a field trip to a manufacturing facility or by a professional in the manufacturing industry visiting the class as a guest speaker

B. Professional Resume: In this assignment, students use word processing software to write and format a professional resume that can later be used to assist in gaining entry level employment in the manufacturing industry sector. The resume lists the student's occupational objective, educational experience, software skills, hands-on skills, and certifications. The resumes are checked for proper spelling, grammar, diction, and formatting.