Glendale Unified School District

High School

February 7, 2023

Department:	Career & Technical Education
Course Title:	Intermediate Engineering
Course Code	5448V/5449V
Grade Level	9-12
Course Credits:	10
School(s) Course Offered:	Clark Magnet High School
UC/CSU Approved (Y/N: Subject):	Yes, “G” Elective
Recommended Prerequisite:	None
Recommended Textbook:	art21.org ca.pbslearningmedia.org/collection/art-school/
Course Overview:	This course is intended to provide students a foundation to build interest in higher education and careers within the various engineering disciplines. The intended outcome of the class is for students to gauge and build interest in engineering as a major field of study at the university level, and to build proficiency in foundational skills necessary to succeed in studying engineering beyond high school. A highly integrated class structure including both lecture and laboratory components provides students opportunities to physically apply principles of engineering to real-world scenarios. Robotics is used as the primary vehicle of content delivery due to its breadth of application and incorporation of several of the primary engineering disciplines including mechanical, electrical, and software engineering. Through nine primary instructional units, students will apply key principles of physics, math, design, and computer science as they pertain to solving engineering challenges. Skills gained include, but are not

limited to, computer aided design, engineering calculation, testing and data gathering, computer programming, and project documentation.

Course Content

Unit 1: Perspectives on Robotics and Engineering (4 weeks)

STANDARDS
2.0 Communications, 4.0 Technology, 5.0 Problem Solving and Critical Thinking, 10.0 Technical Knowledge and Skills, Engineering Design Pathway
C1.0 Understand historical and current events related to engineering design and their effects on society.C2.0 Understand the effective use of engineering design equipment. C11.0 Understand the methods of creating both written and digital portfolios.

A. The first instructional unit focuses on giving students insight as to the role of engineers in the world, engineering as a career, and the various disciplines of engineering as they pertain to robotics. Additionally, historical origins of robotics and engineering are presented and related to present day examples and current events.

B. Using online resources, students will research a particular field of engineering (mechanical, electrical, civil, chemical, aerospace, etc.) to gain an understanding of what career opportunities exist in the chosen field and how the scope of work in the chosen field differs from other fields of engineering. Students will report their findings in a 1-2 page typed written paper. In the paper, students will compare the career opportunities in the selected field of engineering to other engineering fields, comment on the use of robotics and automation in the selected field of engineering, and reflect upon his or her own career interests ambitions after conducting the research. After completing this assignment, students will have foundational knowledge of the scope of work in each major areas of engineering and a more detailed understanding about career opportunities in one particular field of engineering.

Unit 2: Fundamentals of Computer Aided Design (4 weeks)

STANDARDS
2.0 Communications, 4.0 Technology, 5.0 Problem Solving and Critical Thinking, 10.0 Technical Knowledge and Skills Engineering Design Pathway
C1.0 Understand historical and current events related to engineering design and their effects on society., C2.0 Understand the effective use of engineering design equipment., C11.0 Understand the methods of creating both written and digital portfolios.

A. Students learn the role and importance of Computer Aided Design (CAD) in 21 century engineering projects while building proficiency in the application of the tools and techniques required to perform computer aided design work. Key concepts include working in both two-dimensional and three-dimensional space, coordinate planes, orthographic view representations, dimensions, and geometric constraints. Within this unit, students learn the fundamental skills in use of industry-standard parametric solid modeling software which is used throughout the school year in later units and projects. Nearly every subsequent unit incorporates a CAD element as an ancillary objective. After completing this unit, students are expected to be skilled in sketching in two dimensions, placing components into assemblies, applying geometric constraints, managing digital files, and navigating the virtual 3-dimensional viewing space. This unit is split between the first and second semesters to better align with student skills, as explained in the "Key Assignments" section.

B. Students will understand the use and application of robots in manufacturing, space exploration, and dangerous environments.

Unit 3: Mechanical Assembly and Testing (4 weeks)

STANDARDS
2.0 Communications, 4.0 Technology, 5.0 Problem Solving and Critical Thinking, 10.0 Technical Knowledge and Skills, Engineering Design Pathway, C1.0 Understand historical and current events related to engineering design and their effects on society., C2.0 Understand the effective use of engineering design equipment., C11.0 Understand the methods of creating both written and digital portfolios.

A. The primary objectives of this unit are to build student proficiency in following complex, multi-step procedures, reading technical documentation, and interpreting engineering drawings.

B. Students will construct a teleoperated robotic vehicle following plans, test its performance, make necessary adjustments and refinements, and report their findings. This unit provides foundational hands-on skills to be used in the laboratory component of all subsequent units.

Unit 4: Applied Physics and Motor Performance (4 weeks)

STANDARDS
2.0 Communications, 4.0 Technology, 5.0 Problem Solving and Critical Thinking
10.0 Technical Knowledge and Skills Engineering Design Pathway
C1.0 Understand historical and current events related to engineering design and

their effects on society., C2.0 Understand the effective use of engineering design equipment. C11.0 Understand the methods of creating both written and digital portfolios.

A. This unit begins with a lecture component which builds upon and reinforces key principles of physics that all students learned in the Physics class taken in 9 grade. Topics include Newton's laws, forces, speed and velocity, acceleration, power, torque, and performance of direct-current electric motors including linear relationships with electrical voltage and current. This instructional module focuses on units of measure, vector and scalar quantities, problem solving including algebraic techniques, and performing experiments following the scientific method to form a hypothesis and achieve quantifiable results.

B. Students will learn the relationship between torque, force, and radius as it applies to a robot's wheels and its pushing capability, and how to draw a free body diagram of basic forces on a robot vehicle. Additionally, students learn how to interpret motor performance curves and identify key operating points along these curves such as the peak power, stall, and no-load points.

Unit 5: Power Transmission – Gears, Chains, and Sprockets (4 weeks)

STANDARDS

2.0 Communications, 4.0 Technology, 5.0 Problem Solving and Critical Thinking, 10.0 Technical Knowledge and Skills Engineering Design Pathway, C1.0 Understand historical and current events related to engineering design and their effects on society., C2.0 Understand the effective use of engineering design equipment., C11.0 Understand the methods of creating both written and digital portfolios.

A. Students learn the primary components of mechanical power transmission, the differences between them, and the purpose of each. Topics include the geometry and application of spur, worm, bevel, and rack gears, gear ratios, efficiency, support of rotating components, and transmission of mechanical power over distances using idler gears, sprockets, and chains. The unit has a strong emphasis on calculation of gear ratios and validation by physical experimentation.

B. The main idea that students take away from this unit is that while available mechanical power may be limited, the speed or torque of a mechanism can be increased or decreased through gearing. Students also learn of the compromises that must be made due to the inverse relationship between speed and torque when gearing is employed in a fixed-power system.

Unit 6: Friction and Traction (4 weeks)

STANDARDS
2.0 Communications, 4.0 Technology, 5.0 Problem Solving and Critical Thinking, 10.0 Technical Knowledge and Skills Engineering Design Pathway, C1.0 Understand historical and current events related to engineering design and their effects on society., C2.0 Understand the effective use of engineering design equipment., C11.0 Understand the methods of creating both written and digital portfolios.

A. The unit on friction and traction includes, coefficients of friction, normal forces, and the differences between static and kinetic friction. Additionally, students will learn how to estimate, research, and determine the coefficient of friction for different robot wheel materials.

B. Example problems are worked to calculate the maximum force with which a robot can push under both static and dynamic friction conditions. This problem builds upon the previous two units when students are asked to account for different gear ratios, and refer to motor performance characteristics to determine if the wheels will slip or if the motors will stall when the robot faces an immovable obstacle. Students achieve the understanding that adding more power or more torque to a drive system does not always result in more available pushing force, if a vehicle is traction-limited. Finally, students discuss the differences between the theoretical mathematical model of rigid-body friction and real-world traction where surface features and surface deformation effects come into play.

Unit 7: Drive System Design (4 weeks)

STANDARDS
2.0 Communications, 4.0 Technology, 5.0 Problem Solving and Critical Thinking, 10.0 Technical Knowledge and Skills, Engineering Design Pathway, C1.0 Understand historical and current events related to engineering design and their effects on society., C2.0 Understand the effective use of engineering design equipment., C11.0 Understand the methods of creating both written and digital portfolios.

A. Within this unit, students will design, calculate, build, and test a robot drive system to perform within a given set of parameters including speed, pushing force, and maneuverability. This unit incorporates all aspects of units three through seven. In the problem-solving phase, the parameters are fixed and an optimized solution is to be determined.

B. In the laboratory experiment phase, students will select their own design parameters to test their own knowledge and understanding of previous instructional units. Students need to determine key design parameters such as quantity and arrangement of motors and gears, size and arrangement of wheels, and tire friction material. Students also will determine key operating parameters of their design including top speed, maximum pushing force, and performance as it relates to DC motor operating curves. Bringing gear ratio, robot weight, and coefficient of friction into the calculations, students will determine at what point along the motor curve their vehicle will be operating when facing an immovable obstacle. Students will be able to explain what necessary changes would need to be made to gearing, quantity of motors, wheel size, or friction material to achieve more favorable performance in various quantifiable measures.

Unit 8: Object Manipulation and Rotating Joints (4 weeks)

STANDARDS
2.0 Communications, 4.0 Technology, 5.0 Problem Solving and Critical Thinking
10.0 Technical Knowledge and Skills Engineering Design Pathway
C1.0 Understand historical and current events related to engineering design and
their effects on society., C2.0 Understand the effective use of engineering design equipment. C11.0 Understand the methods of creating both written and digital portfolios.

A. Once students have gained knowledge and skills in the design, calculation, assembly, and testing of robot drive systems, they will move on to the study of object manipulation and rotating joints. The principals of force, torque, and gearing are again emphasized now in design of the rotating joints (where these quantities are often much higher in magnitude) to drive lifting arms. focuses on units of measure, vector and scalar quantities, problem solving including algebraic techniques, and performing experiments following the scientific method to form a hypothesis and achieve quantifiable results.

B. The object's weight is considered as well as the weight and weight distribution of the arm and end effector itself. End effector design is explored through various strategies to grab, grasp, or grapple onto objects of different geometric shapes including but not limited to spheres and toroids.

Unit 9: Autonomous Navigation and Microcontroller Programming (8 weeks)

STANDARDS
2.0 Communications, 4.0 Technology, 5.0 Problem Solving and Critical Thinking, 10.0 Technical Knowledge and Skills Engineering Design Pathway, C1.0 Understand historical and current events related to engineering design and their effects on society., C2.0 Understand the effective use of engineering design equipment., C11.0 Understand the methods of creating both written and digital portfolios.

A. This unit branches from the mechanical aspects previously taught and moves into the computer science side of robotics engineering. Students begin by learning the role of a computer program as it relates to autonomous robot navigation. The syntax and structure of the programming language are learned and practiced before experimentation takes place. Students learn how to think logically in steps using flow chart diagrams. Key programming concepts covered include loops, if-else statements, and variables.

B. After learning the basic syntax and structures, students proceed through several sub-modules to learn to read various inputs including light sensors, ultrasonic sensors, encoders, potentiometers, and switches. On the hardware side of this unit, students learn the difference between digital and analog signals, and how analog signals may be converted to digital signals through binary representation. Students then learn how to develop logical code, to take sensor inputs and use them to control motor outputs. The unit serves as a foundation for students to further explore industrial automation systems. Once these foundational skills are acquired, students will apply their knowledge in an autonomous robot navigation challenge.

Projects

Digital Portfolio

Students maintain an ongoing digital portfolio of their work in class throughout the year. The digital portfolio serves as the medium for the instructor to distribute prompts and the students to develop written responses. An example of one of the written response pieces a student would need to create in their digital portfolio is a research project to profile one field of engineering that suits the student’s interests. Students conduct independent research to determine the role and responsibilities of types of careers and projects in the field and report back in writing, referencing sources. Additionally, students must select and profile one university offering majors in engineering and report on the university level curriculum plan, engineering clubs and projects, and what sets the school apart from others. Finally, the digital portfolio will include a resume that each student has developed to include his or her unique information background, and skills.

STEM Connections Questions

Every instructional unit includes several STEM connections questions that to which students develop written responses. The questions are organized to relate each instructional unit’s content to key ideas and concepts in Science, Technology, Engineering, and Math. The quantity and depth of questions vary in each unit. Some questions require independent research, while others require calculation, and others require reflection on a project. The questions main introduce a new idea which builds upon one learned in class or may ask students to apply a concept learned in class to real-world scenarios. For example, one of the questions from the Unit 4 module on applied physics and motor performance asks students to calculate how much power would be are required to lift a roller-coaster car of given mass up a track of given design. The question then further expands to ask students to comment on factors of safety, and to speculate what failure modes or problems could occur if a motor were toe not have sufficient power for the application. These types of questions force students to think analytically and apply engineering concepts to real scenarios.

Motor Driven Winch Experiment

This is a formal laboratory experiment that students perform using testing procedures learned in science classes. Students construct a motor-driven winch mechanism and test the amount of weight it can lift to empirically determine the driving motor's performance characteristics. Weight is slowly added until the motor can no longer lift the load, at which point the stall condition has been reached, and students weigh the load. Students then measure and account for the diameter of the winch spool and perform conversions between units of measure in the English and metric systems. The students also perform a no-load speed test of the motor by indicating a reference point and counting the number of rotations in a one minute time period, over three trials. The test data is then compared with manufacturer's published specifications, percent error is determined, and sources of error are identified and quantified. Results and analyses of this experiment are included within the digital portfolio.

Mechanical Robot Design Challenge

In this project, students apply the principals of physics, math, and engineering to construct a fully-functional teleoperated robot of their own design to achieve certain challenge. The challenge is dynamic and multi-faceted. Using what they have previously learned, students work in small collaborative teams of three or four students per team to create a robot which has a drive system, object manipulator, lifting arm, and vehicle lifting system of their own design. The challenge is defined by several rules and robots are bound by design constraints such as maximum volume, quantity of motors, and types of control schemes. The challenge is to design a robot that can pick up racquetballs and place them into containers as quickly as possible within a two minute time period.

Robots must also have a mechanism to lift themselves completely clear from the ground by grappling onto an overhead beam. The challenge is that it is very dynamic and competitive, with four robots operating at one time. When initially presented, students are typically very overwhelmed by the apparent scope of the challenge, and limited resources to work with. This aspect is intentionally designed to model the unpredictable design challenges students may face in the engineering profession. While competing through several trials, teams have opportunities to evaluate and revise their designs. These opportunities for revision encourage use of the iterative design process.

Three Dimensional Computer Aided Design Model 1 – Teleoperated Robot

In the first semester Computer Aided Design (CAD) project, students become proficient in the tools and techniques required to envision and create designs in virtual three-dimensional space using industry-standard Autodesk Inventor Professional CAD software. The finished result is a complete assembly model of a robot including structural pieces, motors, wheels, fasteners, and drive system components. Our experience has shown that many students struggle with the learning curve necessary to achieve success in CAD and are anxious to begin work in 3D. This project incorporates a "begin with the end" technique we use to teach this component of the class. Whereas CAD would typically be taught initially from the basics of coordinate systems, dimensioning, and geometric sketch constraints, we begin with assemblies of parts in three dimensional space. In this first-semester project students are provided a library of pre-modeled parts, which they join in three-dimensional space using assembly constraints and various view navigation tools. Another element of success in this project is the fact that students have previously completed physical robot models, so they are familiar with the names of the parts and their intended functions and placements. We have seen higher student achievement in employing this "end first" model of learning these advanced techniques.

Three Dimensional Computer Aided Design Model 2 – Mini Sumo Robot

In the second semester Computer Aided Design project, students custom design a mini-sumo robot. The project was developed after extensive research of engaging and challenging educational robotics projects. The mini sumo robot project is something that has been very successfully used in many schools in Japan. The idea is that students must design a fully autonomous robot that is no larger than 10 centimeters square. The goal is for two of these robots to be placed a ring, and for each to attempt to stay in the ring the longest, while attempting to push the other out. Before any programming strategy can take place, students must mechanically design and manufacture the structure of the robot.

Students work in collaborative pairs to first model their robot in CAD. The idea is that since the students have already learned the CAD software with the "end first" approach in the first project, they will now do a traditional workflow project to design from scratch a final product that does not yet exist. Students begin with lines, arcs, and dimensions, extrude and revolve 3D features into parts, and then virtually assemble the parts into a complete 3D model. This is a very detailed, very complex, very precise project that requires excellent spatial and visualization skills. Students must determine precise placement of critical components such as the motors and gearbox, sensors, circuit board, fasteners, and battery. Students must recognize conflicts, interferences, and inter-dependencies between component dimensions and placement to ensure that when the design is manufactured, it will physically assemble as intended. Students must also select what size of wheels their robot will use, for the speed they want it to travel, and justify their selection. Students must position the heavier components for an optimal weight balance to provide the needed traction to stay in the ring. In design, students use precise measurements to the thousandth of one inch to align components within their models. Tolerance of the manufacturing process to be used is discussed and considered in design allowances. Geometric concepts such as parallelism, perpendicularity, symmetry, and collinear and tangent lines are emphasized through the use of detailed sketch constraints, which supplement numerical dimensions in the designs. The challenges in this project are not only in learning the CAD software, but also in learning the geometry behind the design, the math behind the dimensions, and the difficulty in placing the required parts within the volumetric constraints. Students are also taught how to effectively use curves, lines, colors, and positive and negative space to enhance the aesthetic appeal of the vehicle. Once the 3D model is complete, students create a flat pattern drawing of each of the individual pieces to be custom manufactured from acrylic using a computer-controlled laser cutting machine. The end result is a complete, tangible, physical robot model, which is nearly identical to the virtual CAD model. This project reinforces that engineering is not about fabricating components one at a time with hammers and hack saws, but is about performing precision design work using advanced modeling software, and designing for mass production by means of precision computer-controlled machines.

Autonomous Robot Programming Challenge 1

In the first autonomous robot programming challenge, students must program their robot to navigate a given environment without any human input or intervention. The robot must make use of sensory inputs such as ultrasonic sensors and light sensors to gain awareness of its surroundings, and then logically control motor outputs to navigate the course. Prior to this project, students have completed exercises in using each of the sensors, and in the basic syntax and structures of the programming language. Students begin by writing pseudo code to outline their logical strategy. The strategy is analyzed for faults, and then shifted into actual program code, where repetition structures such as while loops and decision making structures such as if-else statements are used. Students configure various sensor inputs and develop algorithms to perform the intended navigation task using the motor outputs. This challenge makes use of the scientific method throughout the testing and revision process. Students must predict what the machine will do based on the code they have written, test and evaluate the results, and revise the code making incremental improvements until optimal performance is achieved. This project makes use of a flow chart based programming language to emphasize the logical progression of the code, and sequence of events in the robot's actions.

Autonomous Robot Programming Challenge 2

The second autonomous robot challenge makes use of the mini sumo robot students have design in the second CAD project. For the mini-sumo robot, students learn the structures and syntax associated with a text-based programming language. Additionally, students make use of specific timing and sequencing using delays and timers.

Students must estimate the master loop cycle time of the program to ensure sensors are read and motors controlled at an acceptable frequency. Students must perform calibration and testing of the robot's analog infrared light sensors while accounting for surface variations and lighting conditions within the classroom. Finally, students evaluate motion planning strategies in which certain elements of code execute only under certain circumstances