Educational Transfer Plan (ETP)

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AP Calculus AB (11th/12th Grade)
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Math, Machines, and Metacognition

0. Abstract

The Stanford Intelligent Systems Lab (SISL) conducts research on decisions under uncertainty and optimization problems with applications to autonomous vehicles. These two math projects will apply calculus principles of optimization and statistical modeling with Bayesian recursion and uncertainty to high school curriculum. Both projects will give students a better sense the complex, multifaceted problems engineers face and resolve in STEM careers using appropriate STEM hardware. Students will also gain exposure to programming languages as the robots used within projects are given commands through the C/C++ language. Finally, students will be given metacognitive opportunities throughout the projects where they will connect their own habits and mindsets to those needed in order to succeed in STEM fields. These projects are suitable for students in calculus who have learned applications of differentiation and for statistics students who are familiar with conditional probability, Bayes' rule, and probability distributions. Programming knowledge is not required but will be taught and presented as part of the design process. Students will be able to practice mathematical modeling, precision, and justifying explanations within these projects.

I. Standards Connection to NGSS or Common Core

1. Focal Standard:

Focal Standard: AP Calculus

11.0 Students use differentiation to solve optimization (maximum-minimum problems) in a variety of pure and applied contexts.

This is the California Common Core Standard for optimization in advanced mathematics (AP Calculus AB).

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2. Active STEM Learning and 21st Century Skill:

Metacognition – students incorporate thinking strategies.
Students will purposely engage in metacognitive reflections on how their habits and mindsets either support or work against math best practices. They will consider why the integration of math concepts and technology is crucial in today's STEM careers, and brainstorm ways that their mindsets can bolster STEM thinking. They will reflect on their work during intervals within lab days and at the end of each lab day.

<u>During the lab/activities, students will reflect on:</u>
- What seems to be working? What isn't working? What evidence is showing me that it's not working?
- What have I done in the past that could possibly be helpful to me during this experience?
- Who can I ask for help? What questions should I ask in order to get an answer that will help me move forward?
- How can I use technology to create a model or prototype? If I'm unsure of how to use technology appropriately, where can I go to get resources? How can I best engage with those resources?

<u>After the lab/activities, students will reflect on:</u>
- In what ways was I successful today? What actions, habits, and mindsets contributed to my success?
- Where did I struggle today? What about the lab/activity made it challenging compared to things that I've done in the past?
- What resources did I use and how did I use them? Was it productive? Where am I still confused?
- How can I take my experience from today and apply it to the broader picture of my education?

21st Century Skill

Critical Thinking and Problem Solving:
Students will solve large-scale problems using math concepts, programming skills, and hardware in unison. Engaging students in hybrid learning environments where they must draw upon multiple sets of knowledge and skills is crucial because such environments attempt to replicate experiences of real-world scientists and engineers.

3. Design Thinking:

Students will work in small teams to solve open-ended problems. The problems will draw upon multiple areas of their prior knowledge such that there is no "one right way" to arrive at a best solution. This will promote students to use creative approaches to solve problems and to more deeply question the methods that they employ to solve problems. Because each project incorporates multiple opportunities for design and feedback, students will be able to build on their models and increase the complexity/creativity of their strategies before the final, graded task.

4. Measurable Objective(s):

- Students will use robotics to solve probability and optimization problems in mathematics.
- Students will use computer programming and algorithmic thinking to connect math concepts to actions of robots.
- Students will use mathematical modeling, precision, and justification to articulate the methodologies and limitations of their work.

5. Assessment:

- **Formative Assessments:** Students will complete class labs (small tasks or activities designed for 90-minute class blocks) where they performing a smaller-scale version of the project. They will submit their models and analysis to their teacher at the end of the class lab. Teachers should give feedback to either individual students or groups on modeling, precision, and constructing an explanation.

- **Final Assessment:** Students will analyze a complex optimization or probability scenario that incorporates math concepts, programming, and line-following robots. In small groups, students will design a prototype solution, model their solution using mathematical tools, and test their prototype on line-following track. After testing, students will reflect on their product and analyze whether it produced results they desired. As Summit Public Schools grades on cognitive skills, students' final grades will be determined by their scores on the following:

  - **Precision:** how detailed are the math calculations within your prototype? How much did your final outcome differ than what you theorized? Why do you think such differences occurred?
  - **Modeling:** what types of models can be created to represent complex math problems, and how do the features of the model communicate or build up to the outcome of the problem?
  - **Compare and Contrast:** how your project experience similar to problems that engineers solve in the real world? How is it different?
  - **Identifying Patterns and Relationships:** how can the optimization principles or probability principles from the opening labs be used to solve much more complex mathematical problems?
  - **Discussion/Contribution:** how can we reflect on our learning as a mathematical community and learn from it?
  - ***For reference***, the Summit Public Schools cognitive skills rubric can be found here.

- ***Extension:*** students will explain how their computer program works (Arduino input to the corresponding movements by the robot). Specifically, they will dissect their code line-by-line and explain how each part relates to the overall process of robot movement and direction they are trying to achieve. Students with background programming knowledge can use the Pololu Robotics to create modifications to their project (assuming that that can troubleshoot and work in a self-directed manner).

II. Fellowship Connections

1. Fellowship Description:

The Stanford Intelligent Systems Lab (SISL) conducts research on decisions under uncertainty and optimization. Many of the graduate students pursue topics such as collision avoidance or autonomous decisions in self-driving cars. The self-driving car must possess decision criteria on how to avoid impact with other cars in a dynamic environment, like a highway. I have learned that many of their problems focus on POMDPs: Partially Observable Markov Decision Processes. This means that only part of the process can be seen at a time and that the machine must be able to continuously make decisions as the process continues and the environment changes. Students and engineers in this lab could be prepared in careers for engineering, particularly anything that involves movement, or computer science. Many of them also to continue to work in labs to conduct research in autonomous vehicles.

My fellowship has taken two directions: First, I learn how computer programs are used in technology and in high school math problems so that I can take real-world applications back to my classroom. Second, I examine (through text written by my sponsoring professor) how high-level engineering and computer science academic texts can be translated for undergraduates and high school students to encourage the study of advanced topics in mathematics and engineering at a younger age.

2. Fellowship Connection to School/Classroom:

I plan to use this experience in two ways: to share and emphasize the importance of real-world applications of mathematics with my students, and to encourage metacognitive thinking during mathematics to encourage student growth through productive struggling.

Students often view their high school math classes as a collection of tests and assessments. When presented with a math project in a real-world scenario, students may struggle to see the applications of what they have learned or the value in learning how to apply their knowledge to projects. However, our society would not continue to develop technologically without research and problem-solving by a globalized workforce of engineers, scientists, and mathematicians. The work that they perform daily is grounded in experimentation and failure, and the steps they take to solving dynamic problems do not come from a textbook. Students engaging in these projects will not only combine math with technology, but simultaneously experience the ambiguity shared by scientists when there is not a clearly-defined "next step."

In order to learn how to progress and struggle productively, students will engage in a series of metacognitive, reflective discussions about their relationship with mathematics throughout the project's duration. Students will analyze their thoughts and feelings throughout the project experience individually, in small groups, and in a whole-class discussion two-thirds of the way through the project. This reflective process is crucial for developing habits, mindsets, and actions of technical thinkers. Students must know that frustration is expected when precision plays a role in the final outcome. And, rather than feeling constrained and hopeless, students must learn that they will advance their case further if they embrace creativity and open-mindedness as they explore successes and failures within their work.

III. Instruction

1. Instructional Plan:

The following information will be given to students at the onset of the project. This is a sample for the AP Calculus optimization project (a similar project plan would be distributed to students for the AP Statistics project). Teachers should feel empowered to adapt this communication as they see fit for their classes, grading structures, and student audience.

I. Summary

Grand Theft Robot is a game of optimization. Using mathematics and calculus, you will design a path for your robot to drop off a package at a secret location and then travel to the Canadian border before the police get there. The path that you design for your robot must be optimal and you must be able to prove that it is optimal. Once you find the optimized path, you will also set the traveling speed of the robot, which should be the lowest speed at which the robot can still beat the police.

In order to prepare you for Grand Theft Robot, we will be engaging in several group activities that involve optimization scenarios designed to give you feedback on how you will do in the overall project. You will work in teams to conduct in-depth analyses and to strengthen your optimization skills through feedback and practice.

It is important that you keep up with the notes and pre-work for this unit because there is only one project before the mid-year report. This implies that whatever you score on your project will significantly impact your grade.

II. Final Product and Checkpoints/Steps

Day 1 -- Conceptualizing Optimization
Day 2 -- Optimization with Geometric Figures
Day 3 -- Path Optimization
Day 4 -- Optimization, Paths, and Robotics
Day 5 -- Grand Theft Robot Day 1 || Problem Analysis and Path Execution
Day 6 -- Grand Theft Robot Day 2 || Written Analysis and Reflection

III. Cognitive Skills

The following cognitive skills will be assessed during Grand Theft Robot:

- Modeling
- Precision
- Identifying Patterns and Relationships
- Compare and Contrast
- Discussion/Contribution

IV. Due Dates

The final reflection for Grand Theft Robot is a timed-write held in class on the last day of the project. If you are absent for the timed-write it is your responsibility to make it up before the mid-year reports are submitted.

All project materials including robot path specifications, mathematical models, posters, diagrams, and other explanations are due before the timed-write. It will be your responsibility to submit them on time. Late work will be penalized.

V. Extra Help

There will be extra problems available on the Math HUB for students who wish to explore optimization further or get more feedback on their work. The worst time to ask for help and understanding is after the project is already over. Be proactive and do extra problems if you think that your understanding of this concept should be improved.

Optimization is a very common math topic in engineering and computer science. Students who wish to pursue STEM beyond high school should do more practice problems and get a deeper understanding because they will see these types of problems, in different and in more challenging capacities, in college.

2. Additional Instructional Context:

These projects were created for Summit Public Schools and intended to be assessed using the Summit grading system. Summit grades using a Cognitive Skills Rubric to give feedback rather than a traditional points or percentage system. Students are given suggestions on how to improve their work throughout the project relative to cognitive skills assessed within the unit. They are then given final cognitive skills grades on the last task.

All handouts and tasks can be adapted to a points-based or percentage-based grading system if desired. Teachers would need to determine what percentage or how many points, if any, would be given to the preliminary tasks and final task of the project. If this approach is taken, the suggested distribution is 80% final task, 20% preliminary tasks.

Lessons are based on 90-minute project blocks where students attend class twice per week. Students complete one warm up/extra notes and one task during each block. Lessons can be modified to accommodate different schedules by changing combinations of notes and tasks. Pre-work videos are typically assigned to students before each lesson. Students must take notes on videos, write down questions or lingering thoughts, and bring notes to class to more deeply engage with complex questions. Pre-work is used in place of class lecture, although class lectures may be used to communicate methods, formulas, and content needed by students completing the projects.

3. Supply List:

General Supplies: (2) Pololu 3pi Line Follower Robots per optimization - $90/robot While student take turns using the robots to test their optimization, a min of 4 robots would be prudent. https://www.pololu.com/product/975 Electric Tape - $3/roll Computer Arduino Platform or Application (free) Tape Measure or Rulers/Yardsticks Stopwatches or Timers		
Calculus:	**Warm Ups/Extra Notes:** Class 1 Class 2 Class 3 Class 4 Class 5 Class 6	**Math Tasks:** Task 1 Task 2 Task 3 Task 4 Task 5 Task 6

4. Bibliography:

1. **Legg, Angela M., and Lawrence Locker, Jr. "Math Performance and Its Relationship to Math Anxiety and Metacognition."** ***North American Journal of Psychology*** **(2009): 471-85. Web.**

2. **Boaler, Jo.** ***What's Math Got to Do with It?: How Parents and Teachers Can Help Children Learn to Love Their Least Favorite Subject*****. New York: Penguin Group, 2009. Print.**

5. Keywords:

- Calculus AB
- Robotics
- Programming
- Optimization

IV. Attachments

Warm Ups/Extra Notes:
Class 1
Class 2
Class 3
Class 4
Class 5
Class 6

Math Tasks:
Task 1
Task 2
Task 3
Task 4
Task 5
Task 6