Curriculum Development For the XRP Robot

An Interactive Qualifying Project

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by

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Abstract

The XRP Platform developed by the OpenSTEM initiative is an inexpensive and easy to use platform for students around the world to learn engineering practices. By aligning the curriculum used to teach with the XRP around proven project based learning methods, the platform can be used with the curriculum to effectively inspire students in the field of Engineering as well as build intuition about the practices effectively. This is achieved by implementing and using a development guide for curriculum that emphasizes the concepts of the NGSS standards for science education.

Acknowledgements

I would like to thank Brad Miller and Professor Joseph Doiron for the opportunity to work on this project and for their support and advice. They believed in me as an individual IQP, and let me pursue a topic I have found very interesting for a long time.

I would also like to thank Bhaavin Jogeshwar, who wrote some very effective parts of the curriculum, helped a lot with moving to Read The Docs and with Sphinx, and helped with the development of a Style Guide.

Authorship

As an Individual IQP, all of the work in the scope of the IQP was done by Akshay Jaitly.

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Executive Summary

The XRP robot is an education platform that is not used to its fullest extent. The incorporation of the Next Generation Science Standards as well as influences from Multiple Literacy in Project Based Learning should create better curriculum to be used for the XRP curriculum.

In this project, a development guide was created to make better curriculum and structure ideas in the curriculum more appropriately. Pages of the curriculum that were lacking good projects and good use of PBL were re-written using the new guidelines. The curriculum now has 9 new and re-written pages.

Manim, an animation engine, was explored for the creation of graphics. While it created good looking graphics, it had a steep learning curve and a required extensive development time.

The curriculum was also moved to a page using Read The Docs. This allows Instructors more freedom on how they use the curriculum, and protects the curriculum from breaking after minor changes.

Chapter 1: Introduction and Background

Developments in manufacturing and hobbyist technology have made robotics more accessible in terms of ease of use and cost. As such, robotics education is being seen as a way to approach education in multiple Science and Technology fields. The LEGO Mindstorms platform gained a lot of interest due to its modular capabilities and visual programming interface, which gave beginners and students an easy way to apply STEM techniques in ways that interested them.

The Mindstorms platform, and uses of platforms and robotics curriculum like it, utilize Project Based Learning (PBL). LEGO Mindstorms had been used successfully to demonstrate and teach robot kinematics [citation here]. While traditional courses focused on the mathematical basis of robot kinematics, the hands-on learning experience gave good motivation and stimulation which provided a better experience for learning. The hands-on design and iteration also provided an opportunity for practicing Engineering design.

NGSS

Good practices in learning science are characterized by the use and intersection of three “dimensions” according to the Next Generation Science Standards. Students should be engaged in Science and Engineering Practices, should be Crosscutting Concepts, and be learning Disciplinary Core Ideas. By this framework, one of the important parts of scientific learning is to give students the ability to apply scientific thinking to the concepts learned.

NGSS standards highlight eight important engineering practices (one of the three dimensions):

1. Defining problems
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using Math and computational thinking
6. Designing solutions

7. Engaging in argument from evidence
8. Obtaining, evaluating and communicating information.

The 7 crosscutting concepts, important for scientific inquiry, are:

1. Patterns

    Patterns and the recognition of patterns influence questions about the relationships between phenomena

2. Cause and Effect

    Investigating the causes of events and how the effects change in different context

3. Scale, proportion, and quantity

    Understanding how to properly abstract systems. At a certain scale, understanding what matters and what doesn't

4. Systems and system models

    Finding a way to test ideas by defining a system with constraints and reasoning about its response

5. Energy and Matter

    Understanding flux and equilibria of systems

6. Structure and Function

    Understanding how the substructures of the system influence the system

7. Stability and Change

    Characterizing change and evolution, as well as stability of systems

These are concepts that are presented as being important across all practices of science, and should be understood.

Using these dimensions, a “conceptual shift” in how we consider science education is proposed. As an example of this shift, NGSS cites what standards should define “models” as doing. While traditional standards regarding the use of models focus on using them as representations, to explain concepts, NGSS proposes a standard where students are able to build models to help predict the behavior of what they are modeling. This is not only more in-tune with how models are used in industries, but also give students an opportunity to practice design thinking, and apply the scientific process. It engages them in developing and using models, which also uses multiple cross-cutting concepts. (“Get to Know the Standards | next Generation Science Standards”)

The standards are made such that students build a deeper understanding and the skills to exploit that deeper understanding, as well as knowledge pertaining to the concepts themselves. The students are supposed to build towards skills like problem-solving by understanding cause and effect and the scientific method.

PBL

Often, Project Based Learning is used to allow students to validate discussions, theorems and ideas discussed in classes. Lectures introduce ideas backed by rigorous logic, and labs are used to prove to students that the theories are valid. These are treated as two discrete and separate approaches. PBL has, however, been shown to be useful when the projects go hand-in-hand with the lessons, guiding them. (Preston)

Multiple Literacies in Project Based Learning (ML-PBL) Curriculum utilizes PBL. It focuses on project based learning in elementary school classrooms. The curriculum follows a framework that promotes project based learning to help students connect with the material in a more natural way. It is built to meet Next Generation Science Standards, where a focus is put on the three dimensions. ML-PBL Curriculum very clearly cites the NGSS 3D standards as inspiration for their framework, but they add “phenomena based” curricula, where the 3D Standards are demonstrated through observation. (“Anatomy of a ML-PBL Lesson | MLPBL Project”)

The Units in ML-PBL curriculum all follow “Unit driving questions”, referred to as DQs. These are questions that encourage students to use the three dimensions to consider the question. One example of a unit in ML-PBL is unit 3.4 -- “Plants”. The driving question for this chapter for students (in the third grade) is “How can we plant gardens for our community to grow plants for food”. Such a question requires students to observe and construct hypothesis on what influences plant growth, as well as design experiments and create models that reflect data collected to make approximations. In doing so, they engage in practices to learn crosscutting concepts, reinforcing their knowledge of the core ideas.

XRP

The Experiential Robotics Platform (XRP) is a robotics platform developed as a part of the OpenSTEM initiative by WPI. The robot itself is a two wheeled differential drive robot which can be programmed using python and blockly. The parts can be 3D printed, which makes it inexpensive to manufacture. The “differential drive” robot is one with 2 wheels. Thus, the robot can drive forwards, backwards, and make turns of arbitrary radius.

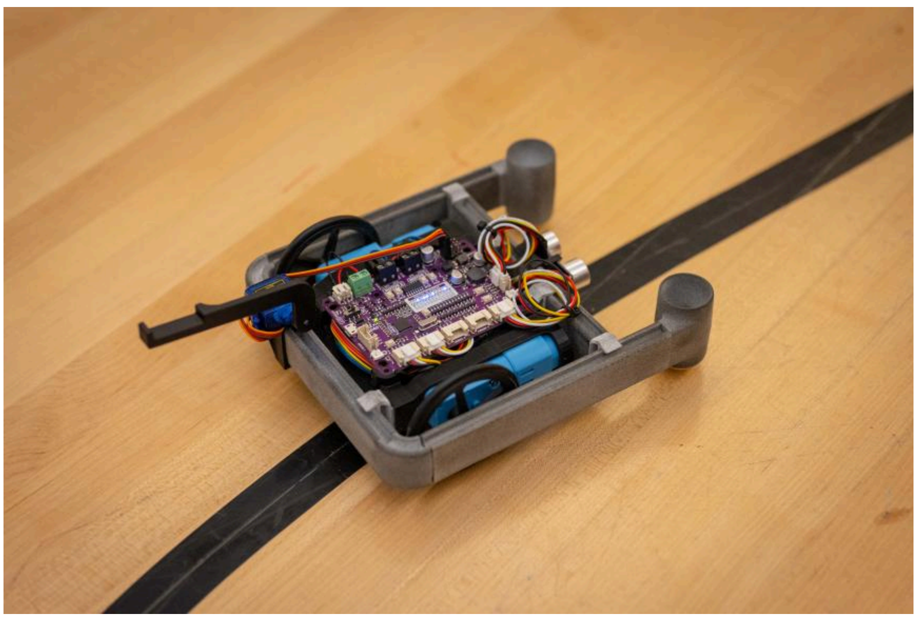


Figure 1: the XRP platform

The curriculum that exists for the XRP derives with students the “kinematic equations of motion” for the robot. These are the equations that model the movement. Given a desired robot speed and turning radius, how fast does each wheel need to turn? The wheels turning at the same speed makes the robot go in a line, while having one wheel turn slower than the other makes it go in a circle. Depending on the speed differential, the length of the turning radius changes (which is why it is called a differential drive vehicle).

The platform presents opportunities for analyzing physical phenomena -- like the kinematics -- but also a lot of problem solving opportunities. The existing curriculum focuses on building knowledge about robotics concepts by applying them on a real robot. There are exercises dedicated to applying the aforementioned kinematic equations and using them to make the robot follow a path.

The curriculum is accessible through a canvas site, which is divided into "modules". These modules are containers for "pages". Each page focuses on part of the module topic. The modules are, in order,

1. Course Information
    - This is quite literally information about the course, including logistics about "joining course platforms"
2. Introduction to the XRP
    - This module introduces the XRP platform as well as motivation and intuition about robots. It walks students through downloading the programming tools and software libraries.
3. Getting the Robot to Drive
    - The goal of this module is to have students understand how to get the robot to drive. The equations of motion are introduced here as well as concepts of "effort vs speed" and how to use buttons on the robot. There is a final challenge to drive while tracing out a shape.
4. Measuring Distances Using Sensors
    - This module has the students learning about how perception works and can be used. It focuses on perceiving the environment with an ultrasonic sensor. Using these, robots are given the opportunity to make decisions about their movement (control law). Students implement "on/off" control and "proportional" control to have the robot carry out tasks after processing sensor readings.
5. Navigating By Following Lines

- This module abstracts the concepts of the control loop by introducing a new form of perception, a color sensor. Students use the color sensor to measure the lines on the ground and follow them. The final challenge is an open-ended challenge where students are meant to use the skills acquired to create “sumo-bots”.

6. Manipulating Objects in the Environment
    - Students are given a servo motor and use it to learn how to manipulate the objects in the environment.
7. Delivery Robot Challenge
    - Students are given a capstone challenge -- they are expected to make the robot navigate in a known environment and move boxes from one point to another. This is meant to exercise all of the concepts they’ve learned so far.

The pages generally present information and then allow students to use the information in a structured or unstructured project using the platform, where a task is expected to be carried out. This is used as both a learning task and a task where instructors can assess the topics that need more work.

The XRP Platform is one with a lot of promise if used the right way. The purpose of this IQP is to find the areas where the curriculum is lacking, and where it can be improved. Then, create improvements and methods to ensure that future development on the curriculum aligns with the concepts that are explored.

Chapter 2: Method

Use Of PBL

The current pages in the curriculum use the platform as a way to demonstrate concepts and topics that are taught to the students. If done right, this form of PBL can reinforce the intuition given in “lecture”. Students, after having the concept introduced to them, should be able to reinforce their intuition with the projects this way.

This does not, however, use the platform to its fullest potential. As discussed before, PBL is most useful when the projects are used hand in hand with the theory and used to explore solutions and phenomena, rather than prove that they exist. This presents an opportunity for improvement. For an example, we can look at the page for “on/off control” of the robot.

Students are expected to make the robot drive forward when it sees it is too far from an obstacle and backwards when it is too close. This concept is simple enough. At the head of the page, the student is told what “control” is and how sensors are used for control.

This introduction goes as follows --

“The main purpose of sensors is to introduce feedback into the system. During actuation, the state of the robot and its environment is continuously changing. Feedback informs the system how much the state has changed and how much more the state should change. Feedback introduces more control over autonomous behavior - a fundamental characteristic of all intelligent robots!”

Following this introduction, students are given intuition for On/Off control-- “In this control scheme, an actuator is turned on until a certain condition is met. When the condition is reached, the actuator is turned off” and given the steps to implement it. This, of course, does not engage students in problem-solving, rather supplies the solution. This example also introduces a second problem with the curriculum as it stands. Background and terms are often either assumed or glossed over. The introduction of the idea of “robot state” here seems unexpected, since this is the first students may be hearing about it.

The XRP curriculum, thus, stands to benefit from a slight re-structuring of the curriculum. In the style of the Next Generation Science Standards, it may also benefit from a “conceptual shift” in how curriculum is developed, and how projects are introduced into the curriculum. The big ideas and projects in the curriculum are creative and should be continued, but the way intuition is built may be able to be changed.

Distribution and Ease of Access

The platform that the XRP curriculum is distributed using also presents an opportunity for improvement. Canvas requires a payment by the organization hosting the site. WPI is required to pay a significant amount for every student that is signed up for the Canvas Course. Canvas does not support source control, so there is only one version of the course. This means that developments made to the curriculum after it is published may be difficult. If developments are made while an instructor is using an older version of the site, the activities may change in the middle of the course. One day, the instructor could be working to explain controlling behavior with an activity that requires using an ultrasonic sensor, and the next it could be changed to a completely different activity. It would be beneficial for instructors to have access to previous releases of the site.

To add, instructors often want to use their own institutions’ LMS instead of canvas. A platform is needed that also makes lessons easy to export, so that they can be uploaded to the LMS that teachers want to use.

WPI Lib(“FIRST Robotics Competition Control System”), maintained by WPI and Brad Miller, the advisor to this project, requires extensive documentation. It is a software library used by high school robotics programs for development of software for robots competing in the FIRST Robotics Competition. As a publicly published library it requires extensive documentation.

This must have different versions, an ability to publish stable versions, source control, and be accessible around the world by numerous people. “Read The Docs” was used. (“Home | Read the Docs”). Read the docs is an open-source software that publishes and hosts websites featuring documentation. It enables source control, publishes to a globally accessible website, and enables downloading pages as well. Read The Docs formats the documentation using Sphynx, which has extensive documentation itself, and formatting options that should satisfy the needs of course development.

Teacher Interview

In talking to Charlotte Corbette, A teacher from the English High School in Boston, the lack of design thinking exercises was made clear. The Curriculum has opportunities for development of software or solutions, but no chance for students to iterate on their solutions, which was mentioned as an important part of a project based curriculum, especially one meant to be a part of an introductory engineering course.

Charlotte has her students create journals, and log their questions and use of design thinking skills at the end of each week. This is a good practice, and is one that the curriculum should lend itself well to well. The development of the curriculum should take into account, as a big part, this part of the “science and engineering practices”.

Visuals

The XRP Curriculum is word and math heavy. Concepts like the differential drive are explained without the visuals that would greatly benefit the discussion. The visuals for the differential drive are images that are meant to illustrate vectors for wheel speeds. A difference in wheel speeds makes the robot turn in an arc, which is explained. The reason for the phenomenon, however, is not shown. The vectors are another concept that has not had an introduction, and reasoning with the visuals given requires a level of visual thinking that may be reserved for students that already have intuition about differentially driven vehicles.

Grant Sanderson is a youtuber and mathematician that publishes videos for math education. Grant Sanderson (who goes by 3 Blue 1 Brown) created a software library in the programming language Python for mathematical animations in order to communicate mathematics concepts better(3b1b). Manim is regarded as a visually stunning, easy to use, and effective library. Manim will be explored as a tool to create replacements for current visuals.

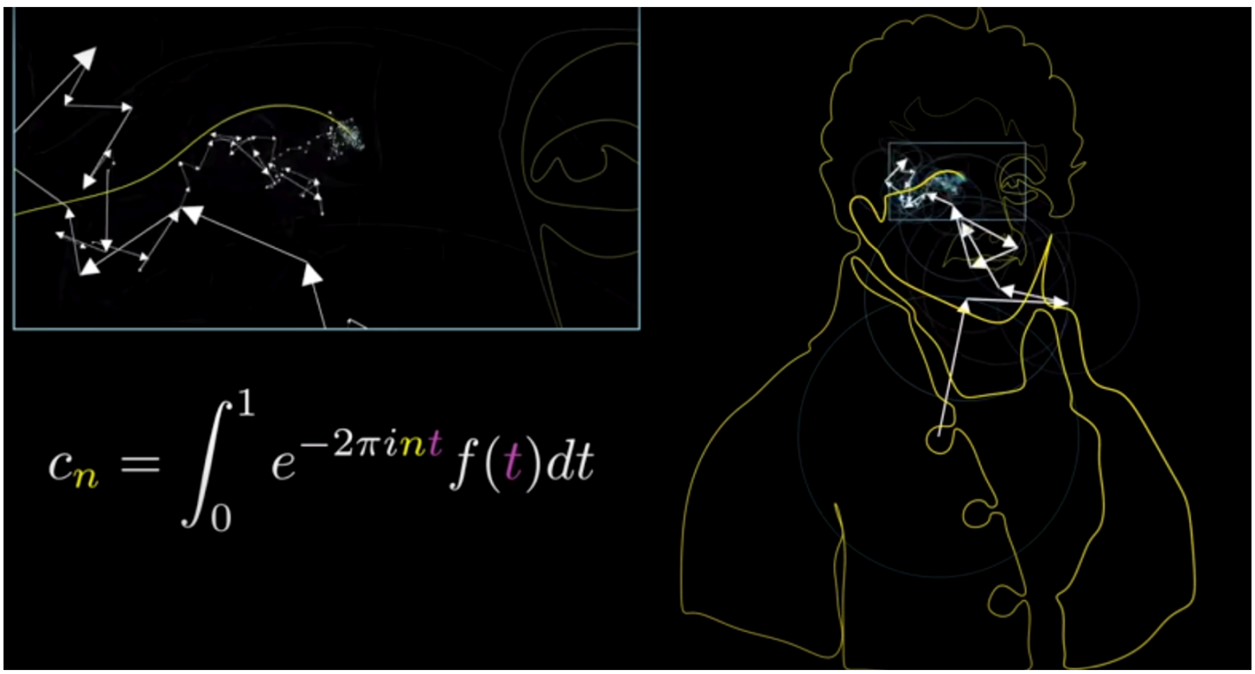


Figure 2: A screen capture from a 3b1b video -- “but what is a Fourier series? From heat flow to drawing with circles” built using Manim

Chapter 3: Results

Development Guide

The development or re-development of future or existing curriculum should occur in a way such that the XRP robot is used to its fullest extent. As such, a guideline for course development that aligns with NGSS standards, and is inspired by ML-PBL curriculum development practices was developed.

Terminology

- “Modules and Pages”

  The canvas site has “modules” and “pages”. This terminology is preserved. The chapters/units are modules and the individual pages that make up the Module are the pages.
- Section

  A page is broken into sections. Each section has a specific type. These can be sections which talk about background, mention activities, or perform another (specific) function. These sections have “types”.
- Idea

  The ideas are what students should be building intuition on or towards at a point in the course. Each page and each module are centered around an idea. Each idea feeds into the next.
- Big Idea

  This is the idea that spans the entire module. The pages in this module work towards building the idea.
- Scenario
  - This is the activity or thought experiment used to explore the idea and reason about it. The scenario should, as often as possible, focus on phenomena or practices noticed on real platforms like the XRP.

Development Pipeline

The development guide itself is divided into 3 sections, “Considerations”, “Building an Idea”, and “Page Sections”.

The development process should be centered around the question -- “What should the students come to conclusions about?”. Their reasoning skills are developed (including their use of practices and crosscutting concepts) when the unit requires them to come to conclusions on the activities themselves. When developing a module or a page, this should be answered first. Considerations (like answering this question) are needed in order to start writing any module or page. The “considerations” are made to enforce the sequence of ideas that was lacking in the current iteration. For instance, the example of students being required to use the “robot state”.

There are listed considerations of “background”. A developer is required to come up with a thought experiment or activity to build intuition about their idea, and is required to consider the background that is needed to reason about the problem. In doing so, the background needed to understand and reason about the idea is inherently taken into account.

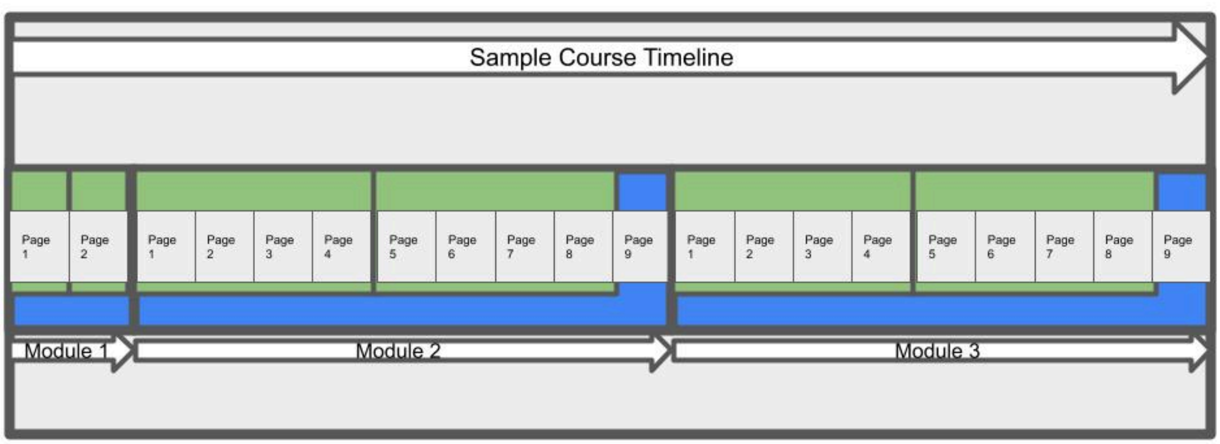
There are considerations on the “idea” as well. The idea is formed as a question, one which presents an open ended opportunity for students to think. As an example, there can be a lesson where students are meant to think about “how the decision making processes of the robot work for lower level control”. Note that the idea poses what intuition should be built towards, and not the conclusions that are expected to be made. This is more in line with the NGSS standards and ML-PBL method, where a student's ability to reason is developed and used to reinforce ideas.

The ideas present in a chapter are sequential -- one idea feeds into the next. For example, “how the decision making processes work” is needed to understand “why is feedback from the environment useful?”. These ideas work hand in hand. So, when building the module it makes sense to work backwards. The big idea is developed first, and spans the entire module. Then, the “considerations” are made -- including the activity and the background needed to build intuition.

The background informs the sequence of topics recursively. If a course content developer realizes a piece of background needed is non-trivial, a new idea is formed around said idea, and a page is made to tackle that idea. When developing this page, the same considerations are made. This helps build the sequence of ideas, as every idea is necessarily leading into the next.

Activities and Page Sections

The page sections are divided into three types. These are “background”, “Motivation and Development”, and “Design Thinking”. The background section is simply the section where trivial background or required theory (that does not require a new page) is introduced. This could also be specific tips on “python programming”. One example of a background section is information on the circumference of a circle, which is used in a thought experiment later in order to develop intuition about driving and getting the distance traveled.



A graphic showcasing a sample course timeline with nested sequential Ideas
Big, Module spanning, ideas (Blue)
Smaller ideas (Green)
Page-spanning ideas (Grey)

Figure 3: Showing how smaller ideas can be composed, building to big ideas

Motivation and Development sections serve two functions. The first is introducing the scenario. This sets the context (“Motivation”) for using the NGSS Science and Engineering practices. Once this scenario is introduced, the section should focus on guiding questions or sub-activities. This is the “Development” section. The student is guided through problem solving and applying practices, while given leeway to reason themselves.

Finally, the Design Thinking section is a section where simple questions are used to help the student iterate on their solutions. This directly addresses the suggestions by Charlotte, and should be a help in classrooms by introducing Engineering Design Principles. These questions help students iterate on their projects and should give them an opportunity to challenge themselves and their own solutions, as well as analyze phenomenon they see. For example, when implementing the On/Off controller, where the robot either goes forward by full throttle or backwards by full throttle, students may be asked if they see any inefficiencies. Students should be able to reason that the robot goes faster than it needs to, and sometimes overshoots -- or at least results in very jerky movement. This leads to them trying to slow down the movement as it gets closer to the goal, which is a crucial part of the improved “proportional control”.

The page sections are, crucially, not required to all exist in every page. A page may exist with just the “Motivation” and “Design Thinking” sections, where a scenario is introduced and students are expected to reason about it on their own. These make good assessments, where instructors can find concepts that need more work.

Porting from Canvas

Read The Docs was relatively easy to implement, and a significant part of it was copying the curriculum from the canvas site. However, the curriculum was missing a comprehensive Style Guide.

This resulted in disconnected and incoherent style. The addition of section “types” was meant to, in part, solve this problem. The style guide was necessary to have consistent formatting. The current version of the style guide focuses on lists, code, images, and page structure.

Course Development Examples

Two modules were selected for modification. These are the modules for “Driving” and “Sensing”. Some of the pages in each were modified to build towards coherent ideas and abilities in the style of the newly developed guide.

The following pages were added or changed :

- Big Idea -- How does the wheel movement affect robot movement? How can we use and describe this?
  - Page Name -- How Far Have You Driven?
    - This added necessary background to the Differential Steering section. It engaged students in mathematical and spatial reasoning to find descriptions for robot movement.
  - Page Name -- How Many Times Have The Wheels Turned?
    - This page added motivation for learning skills needed in the next page, where students use feedback from the sensors to find the distance traveled. This also serves as background for activities in the next module.
  - Page Name -- Differential Steering
    - Differential Steering was improved by adding that background, and graphics that guide students through describing and reasoning about differential driving phenomena.
- Big Idea -- How can we decide the behavior of the robot? How can we modify that? What does it depend on?
  - Page -- Controlling Behavior: Introduction

        - This introduced the idea of controlling behavior, and motivation for using feedback. It also introduces a thought experiment that students can use as an analogy to understand controlling behavior.
    - Page -- Controlling Behavior: Bang Bang
        - Students are expected to come up with a Bang/Bang controller on their own, only after being asked a few questions about controlling behavior. They are then given an opportunity to improve on their work by implementing the engineering design process.
    - Page -- Activity: Trains!
        - Bang/Bang controllers are used in an activity to find where the controlling behavior fails. This is also just a fun experiment
    - Page -- Controlling Behavior: Proportional Control
        - The students guiding questions on the engineering design process are used to find better controlling behaviors. Mainly, they are guided through proportional control.
    - Page -- Wall Following
        - Wall following requires applying control laws in ways that aren't explicitly stated in their derivation. Using this activity helps students exercise their skills on applying tools and finding patterns and similarities between the two scenarios.
    - Page -- Improving Driving Forwards
        - This does the same as the previous page, except it also applies talking about control laws to explain a method that students have been using thus far without understanding.

One example of a big change is how each page builds towards an idea, and the background for each idea is presented, so students can create improvements on their own. In order to find how to do wall following, students need to understand the ways they can implement control algorithms, and then figure out what they can change about the control algorithms to get desired behavior. So, students are introduced to a thought experiment meant to get them to reason about what the simplest controller may be, and then asked to improve on it given some guidelines. These are the bang-bang controller and proportional controller respectively. In following all these thoughts, students come to a better appreciation and understanding of the role of perception in robotics, as they are required to implement perception and concepts that rely on perception.

Exploring Manim

Multiple short animations were created using Manim. Animations were created to demonstrate multiple concepts, two of which are Encoder Value clicking and Differential Driving, in order to facilitate reasoning in students.

The animation for Encoder Value iteration showed a wheel with 60 spikes rotating. The top of the wheel is zoomed onto. Each time the wheel rotates 1/60th of a full rotation (which is visible as the wheel rotates slowly) a spoke is at the center of the screen and a counter iterates. This counter counts up to 120 counts, which students have to reason is 2 rotations.

For differential driving, the car is shown driving in an arc, and the trajectory of each of the wheels is shown. The inner wheel creates a smaller arc than the outer wheel. These are compared in order to show students the difference in size. Some mathematical reasoning is carried out.

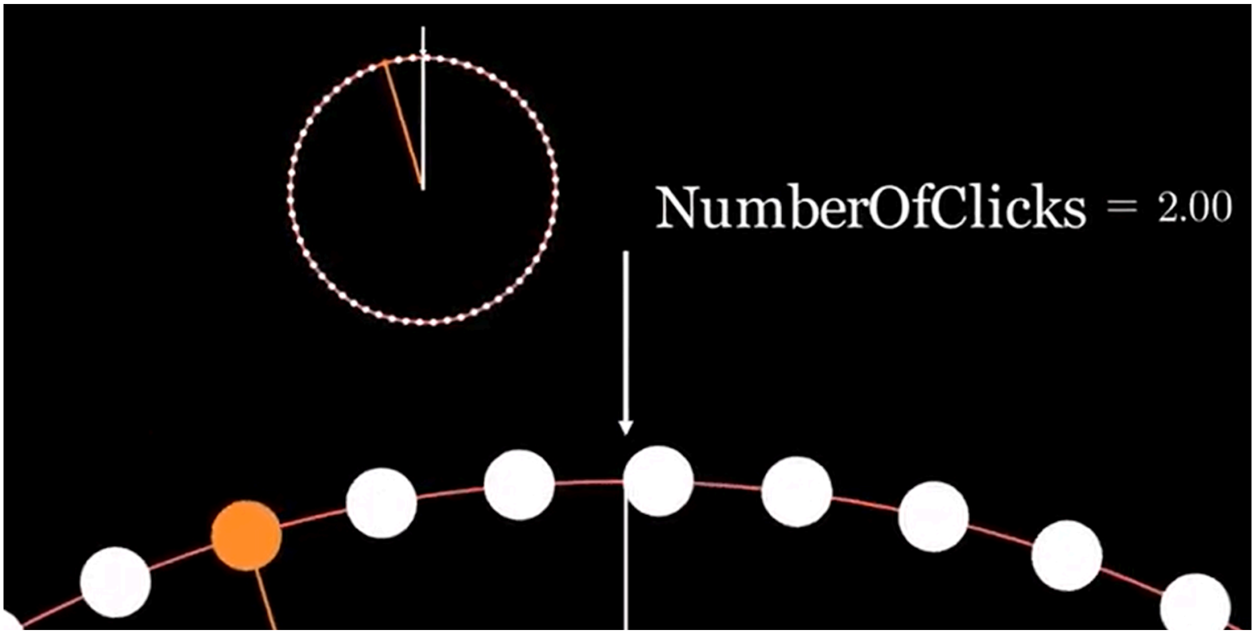


Figure 4: Screen capture from the Encoder Value animation

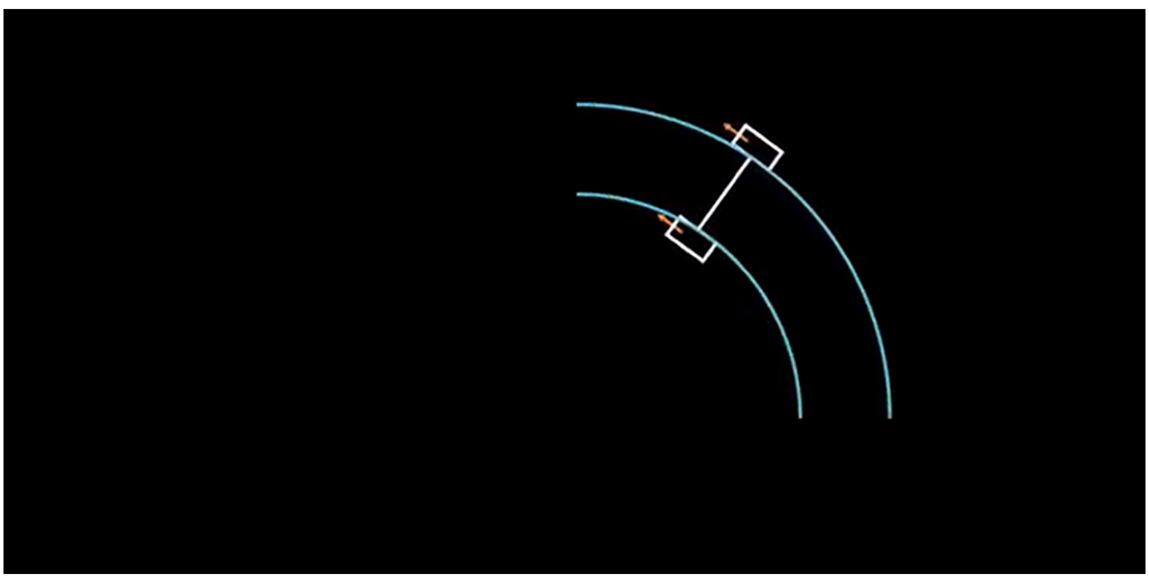


Figure 5: Screen capture from the differential driving animation

The animations themselves were difficult to do in the span of this IQP, since Manim does require a learning curve. It seems to be a useful tool.

Chapter 4: Conclusions

The XRP platform stands as a very promising platform for Project Based Learning, but the curriculum should be built with this application in mind. The proposed framework for development aligns with standards and practices that make sure the platform is used properly, and newly developed pages for the course are now using NGSS standards. However, the new framework is untested. No definitive claims about use can be made until then. It is hoped that, since this aligns with theory, the newly developed course material will help students reason and build engineering interests and skills in all three dimensions, as well as help instructors evaluate proficiency.

The usage of Read The Docs should be a better platform for instructors, and allow for more flexibility in teaching as well as a better distribution platform. Future work on the curriculum can be done directly in Sphynx, and be protected by version control.

This future work should include the development of more activities that assist the instructors in assessment, as well as re-writing the modules that exist to follow the development guidelines. Once this is done, a project can be implemented to compare the two methods.

Future work may also include using the Manim library to create animations. This was one of the exploration avenues for this IQP. It was not the easiest to use, however, with enough experience and time it should be possible to make good visual animations to explain the phenomenon that needs to be communicated.

References

3b1b. "3b1b/Manim: Animation Engine for Explanatory Math Videos." *GitHub*, 15 Feb. 2023, github.com/3b1b/manim. Accessed 30 Apr. 2023.

"Anatomy of a ML-PBL Lesson | MLPBL Project." *Open3d.science*, 2023, mlpbl.open3d.science/curriculum/lessonanatomy. Accessed 30 Apr. 2023.

"FIRST Robotics Competition Control System." *FIRST Robotics Competition Documentation*, 2023, docs.wpilib.org/en/stable/index.html. Accessed 30 Apr. 2023.

"Get to Know the Standards | next Generation Science Standards." *Nextgenscience.org*, 2023, www.nextgenscience.org/get-know-standards. Accessed 30 Apr. 2023.

"Home | Read the Docs." *Readthedocs.org*, 2023, readthedocs.org/. Accessed 30 Apr. 2023.

Preston, Teresa. "A New Research Base for Rigorous Project-Based Learning - Kappanonline.org." *Kappanonline.org*, 24 Jan. 2022, kappanonline.org/research-project-based-learning-de-vivo/. Accessed 30 Apr. 2023.

Appendix A: Example Lesson

/ Controlling Behavior: Bang Bang

Controlling Behavior: Bang Bang

Parking your XRP

You want to create a control law that parks your XRP at a set distance of 20 cm from a wall. You know that, in order to do that, you only need your distance sensor!

In order to build your control law, you build a table. For each of these scenarios, do you want to go forwards or backwards?

Title

Sensor Input	Action, (go forwards or backwards?)
You're a lot closer than **20 cm away**	
You're a little closer than **20 cm away**	
You're **20 cm away**	
You're a little farther than **20 cm away**	
You're a lot farther than **20 cm away**	

Try implementing this table using if statements on your robot. How many if statements would you need?

Design Thinking

What are some problems you're running into?

- Does the robot stop?
- Does it move too fast?
- Does it move too slow?

Why are these problems happening, and how can they be solved?

Appendix B: Development Guide

Considerations:

- What do you want the students to think about, or what do you want students to come to conclusions about? This is the “idea”. The idea can be built towards during the entire course, a module, or a page. This is referred to as the “span of the topic”.
    - For example, you could want students “to consider how decision making processes work for lower level control” over the span of one page. This could be the idea.
    - This does not ask what the conclusions you want the students to come to, but rather what topics they should come to conclusions about. If the conclusions are specific, like deriving the kinematics of the robot, which only has one answer, it may be a good idea to rephrase the topic. You may say the idea was to consider what influences the robot motion and in what way.
- What scenario will build intuition for students, such that they can think more about the idea?
    - This can take the form of a thought experiment, activity, or something else. This is the “motivation” for considering the idea.
- What background is needed?
    - Ideas build off each other. Sometimes technical or ideological background is needed to either carry out activities or to properly come to conclusions.
    - What is the best way to introduce the background?
        - Are there previous ideas that can be extended to incorporate the background?
        - Can the background be built towards independently, and framed as its own idea?
        - Is the background trivial enough that it can be introduced in a section at the top of the page?

Building an Idea:

- Start with the “big idea” -- the Idea that spans the module. Find the activities and background needed to fully understand it.
- Each of those activities / background ideas becomes its own page. These activities and background ideas will need pages before them as well. Recursively introducing background ideas as their own pages is how modules are built.

Page Sections:

- The page sections have types.
  - Background
    - When the Page idea’s background is not significant enough to warrant an entire new page, the background is put in its own background section. This section name should reference the background being built. (A background section can be named “About Circles”)
    - If the background is a tip on python programming, name it “Python Programming Note”
  - Motivation & Development
    - This is where the question/scenario is introduced. The scenario is the context in which intuition towards the idea is developed.
    - Once the scenario is introduced, the section should focus on guiding questions and sub-activities. These are places where you could walk the student through problem solving. Enough leeway should be given to the student to find their own conclusions -- these are just guidelines and guardrails to problem-solving.
  - Design Thinking
    - A section called “design thinking” should be added after an activity.
    - Design thinking is where the student is encouraged to iterate on the solution they found. What went wrong? How could it be solved? Students may be encouraged to measure certain parts of their solution -- “how fast does the robot go where you need it to?” “How smooth is the movement?”
    - This can then be used to introduce the next idea, which may solve some of the problems faced by the students in their current solution.
- Pages may not have all of these sections. A page that introduces a standalone activity (possibly as a capstone or evaluation) could just introduce a problem and encourage students to solve it, then ask questions about improvements. This would have a Motivation section (without development) and a Design Thinking section.