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# Designing for Collaboration: An Engineering Notebook to Scaffold Collaborative Problem-Solving in Middle School Robotics

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**Abstract:** Engineering notebooks are pervasive in K-12 robotics as a record of work throughout the competitive season. While these team notebooks are designed to document the engineering design process and students' learning, they have the potential to foster effective collaboration, with students working together rather than in parallel. Capitalizing on this potential, we introduce a new type of robotics (VEX IQ) engineering notebook designed to facilitate collaborative learning for middle schoolers. By integrating pair programming, the Engineering Design Process, and structured prompts for team and code reflection, our notebook serves as an intervention that transforms documentation practice, scaffolds collaborative problem-solving, and makes collaboration a central tenet of the engineering experience.

## Introduction

Engineering notebooks serve as a record of work completed by teams of engineers who use documentation to support ongoing development. These notebooks help to scaffold the growth of engineering skills such as the Engineering Design Process (EDP) (Han et al., 2023), increase student engagement (Hertel et al., 2017), encourage reflective thinking (Rodgers, 2002), and facilitate problem-solving during project-based learning experiences (Berland et al., 2012; Mein & Convertino, 2022). However, in a K-12 competitive robotics context, these benefits are often unrealized. While engineering notebooks are critical, providing opportunities to win awards and serving as a guideline for the EDP, many teams struggle to use them as true collaborative tools (Sudano & Avvento, 2024). Common challenges that limit their use as collaborative tools include students working in parallel rather than together, one team member dominating while others disengage, and documentation becoming a retrospective chore rather than an active problem-solving tool. Such collaborative breakdown leads to fragmented understanding, avoidable mistakes, and ineffective communication between team members (Le et al., 2018). Our work aims to address this gap by reimagining the engineering notebook as an active intervention that embeds collaborative practices directly into the documentation of the EDP. Rather than assuming collaboration will occur naturally, we design explicit structures and activities (Weinberger, 2011) that make teamwork unavoidable and productive.

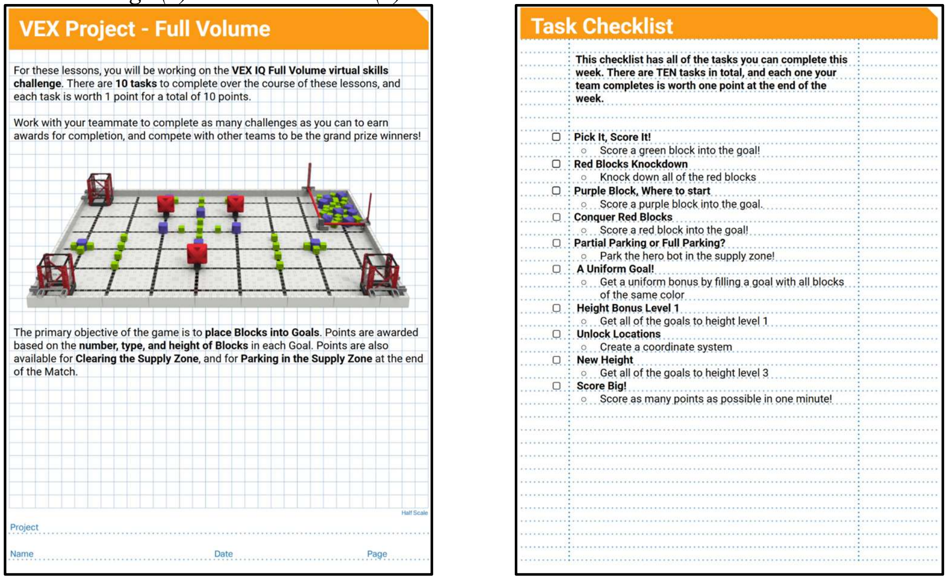
## VEX Full Volume challenge

Our VEX engineering notebook was designed as a companion to the VEX IQ "Full Volume" virtual challenge. In this challenge, students work through pair programming activities following the structure provided by the notebook. Students are paired together and asked to program a robot in VEX VR to pick up blocks of different sizes and drop them in various goals, with additional points for strategic decisions. As part of this challenge, students complete ten distinct tasks of increasing complexity. These tasks range from scoring a single block in a goal post (see Figures 1a & 1b) to maximizing points scored in one minute. After these tasks, students are instructed to document their process and reflect on their learnings through the engineering notebook.

As a metacognitive strategy to scaffold student learning and prevent documentation from becoming a chore rather than a meaningful learning experience, we position documentation as a central component of each task. This is done by grounding our work in engagement and motivation frameworks, particularly self-determination theory (Barata et al., 2013; Ryan & Deci, 2000). We employ gamification strategies by providing bonus points for completing documentation tasks involved in collaborative coding and team reflection activities. Additionally, we leverage the task checklist page to help both the students and instructors monitor progress and completion of tasks (see Figure 1b). Embedding these elements within this engineering notebook reframes documentation as a goal-directed, collaborative behavior. These activities are intended to support students in tackling increasingly complex tasks by encouraging reflection on prior successes and challenges while fostering key motivational skills such as self-monitoring and self-evaluation in both their coding and group work (Kanfer, 1990).

**Figure 1**

*VEX Challenge (a) & Task Checklist (b)*



**VEX Project - Full Volume**

For these lessons, you will be working on the **VEX IQ Full Volume virtual skills challenge**. There are **10 tasks** to complete over the course of these lessons, and each task is worth 1 point for a total of 10 points.

Work with your teammate to complete as many challenges as you can to earn awards for completion, and compete with other teams to be the grand prize winners!

The primary objective of the game is to **place Blocks into Goals**. Points are awarded based on the **number, type, and height of Blocks** in each Goal. Points are also available for **Clearing the Supply Zone**, and for **Parking in the Supply Zone** at the end of the Match.

Half Scale

Project

Name Date Page

(a)

**Task Checklist**

**This checklist has all of the tasks you can complete this week. There are TEN tasks in total, and each one your team completes is worth one point at the end of the week.**

☐ **Pick It, Score It!**
  ○ Score a green block into the goal!
☐ **Red Blocks Knockdown**
  ○ Knock down all of the red blocks
☐ **Purple Block, Where to start**
  ○ Score a purple block into the goal.
☐ **Conquer Red Blocks**
  ○ Score a red block into the goal!
☐ **Partial Parking or Full Parking?**
  ○ Park the hero bot in the supply zone!
☐ **A Uniform Goal!**
  ○ Get a uniform bonus by filling a goal with all blocks of the same color
☐ **Height Bonus Level 1**
  ○ Get all of the goals to height level 1
☐ **Unlock Locations**
  ○ Create a coordinate system
☐ **New Height**
  ○ Get all of the goals to height level 3
☐ **Score Big!**
  ○ Score as many points as possible in one minute!

(b)

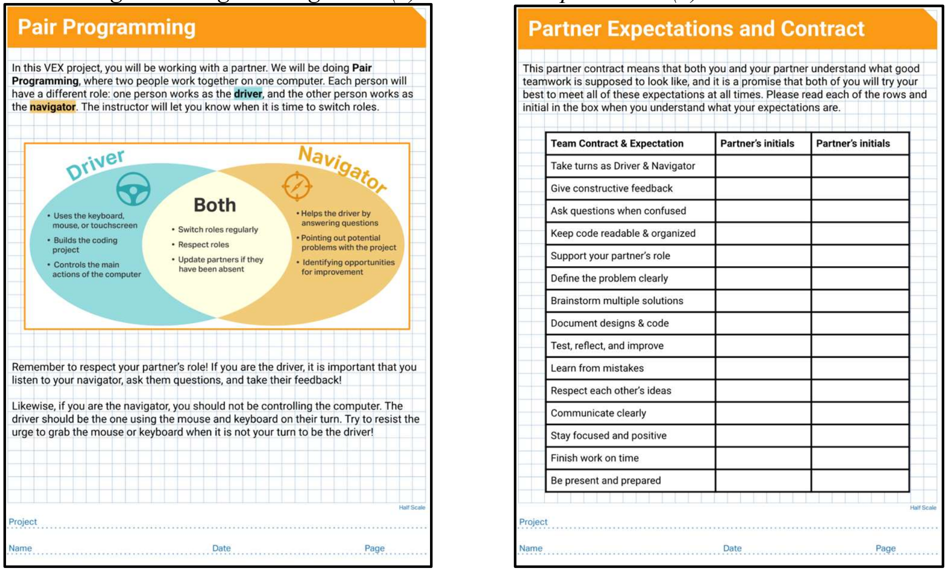
## A notebook designed for collaboration

Common collaboration issues that occur in VEX teams are that students work in parallel rather than together, and engagement is often not shared equally between team members. To address these challenges and ensure collaboration throughout the design process, we designed the notebook around three interconnected principles that help to foster genuine teamwork:

- **Structuring the Engineering Design Process Collaboratively -** Our notebook explicitly introduces the EDP principles (Define, Develop, and Test) as an iterative cycle that teams perform together. Each task within the notebook follows this structure, requiring students to collectively define the task goal, develop code as a pair, and jointly test and evaluate their solution. This approach reflects the collaborative nature of contemporary engineering practice, where engineers rarely design in isolation (Borsato & Peruzzini, 2015), while preventing the common pattern where students divide and conquer rather than work together.
- **Establishing Explicit Collaborative Roles -** To prevent the common issue where one student dominates the computer while another disengages, our notebook introduces the Pair Programming methodology that assigns students to one of two roles: the Driver, who controls the computer, and the Navigator, who guides and suggests edits. Students are required to switch roles frequently throughout each task (see figure 2a). By defining these roles explicitly, the notebook provides a clear framework for interaction, encouraging shared responsibility, active listening, and ensuring both students remain engaged in the problem-solving process (Denner et al., 2021).
- **Creating a Shared Team Contract -** Before beginning the project, students sign a "Partner Expectations and Contract" (see Figure 2b), which requires them to agree on principles of good teamwork, such as giving constructive feedback, supporting each other, and respecting each other's ideas. This practice establishes positive group norms from the outset and creates a shared understanding of what successful collaboration entails (Brannen et al., 2021). This contract serves as a reference point throughout the project that students and teachers use during team reflections after each activity.

**Figure 2**

*Establishing Pair Programming Roles (a) & Partner Expectations (b)*



**Pair Programming**

In this VEX project, you will be working with a partner. We will be doing **Pair Programming**, where two people work together on one computer. Each person will have a different role: one person works as the **driver**, and the other person works as the **navigator**. The instructor will let you know when it is time to switch roles.

Driver

- Uses the keyboard, mouse, or touchscreen
- Builds the coding project
- Controls the main actions of the computer

Both

- Switch roles regularly
- Respect roles
- Update partners if they have been absent

Navigator

- Helps the driver by answering questions
- Pointing out potential problems with the project
- Identifying opportunities for improvement

Remember to respect your partner's role! If you are the driver, it is important that you listen to your navigator, ask them questions, and take their feedback!

Likewise, if you are the navigator, you should not be controlling the computer. The driver should be the one using the mouse and keyboard on their turn. Try to resist the urge to grab the mouse or keyboard when it is not your turn to be the driver!

Half Scale

Project

Name Date Page

(a)

**Partner Expectations and Contract**

This partner contract means that both you and your partner understand what good teamwork is supposed to look like, and it is a promise that both of you will try your best to meet all of these expectations at all times. Please read each of the rows and initial in the box when you understand what your expectations are.

| Team Contract & Expectation | Partner's initials | Partner's initials |
|---|---|---|
| Take turns as Driver & Navigator | | |
| Give constructive feedback | | |
| Ask questions when confused | | |
| Keep code readable & organized | | |
| Support your partner's role | | |
| Define the problem clearly | | |
| Brainstorm multiple solutions | | |
| Document designs & code | | |
| Test, reflect, and improve | | |
| Learn from mistakes | | |
| Respect each other's ideas | | |
| Communicate clearly | | |
| Stay focused and positive | | |
| Finish work on time | | |
| Be present and prepared | | |

Half Scale

Project

Name Date Page

(b)

These structural features create the foundation for collaboration, but the notebook's primary mechanism for facilitating collaborative problem-solving lies in its recurring reflection activities, which we describe next.

## Activities for collaborative problem-solving (CPS)

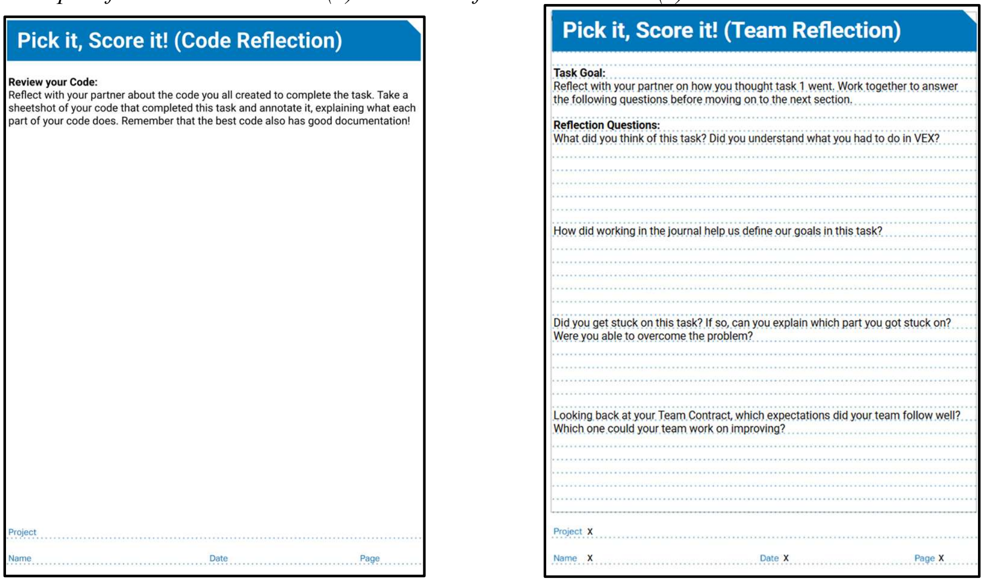
The notebook's core contribution is its set of recurring activities designed to elicit and scaffold collaborative discussion at key moments in the problem-solving process. These activities align with the "Test" phase of the EDP, ensuring that evaluation and iteration happen collaboratively rather than individually (Sankaranarayanan et al., 2021). Each of the ten tasks is followed by two distinct reflection sections that transform documentation from a passive record into an active site for joint sense-making (Zhang et al., 2024).

**Code Reflection:** After completing a programming task, students must screenshot their code and collaboratively annotate it to explain what each part does (see Figure 3a for description). This activity requires students to move beyond simply producing functional code. Moreover, the act of generating explanation (self-explanation) is a known strategy shown to support deeper learning in several domains (Rittle-Johnson & Loehr, 2017; Wylie & Chi, 2014), especially in computer programming (Fabic et al., 2020). In addition to a deeper understanding of the content, reflecting on code generated through pair programming can help students come to a deeper shared understanding of the content through discussion and documentation. For example, rather than one student saying "this loop works," both partners must articulate why the loop is needed, how it functions, and what would happen if it were changed. This dedicated space for collaborative reflection on the code transforms documentation from a solitary task into a shared sense-making activity, forcing partners to articulate their logic and build a common understanding of their solution (Sankaranarayanan et al., 2021). It also provides a tangible record of the team's technical solution and the reasoning behind it, which becomes critical for iteration in later tasks when students need to build on previous code.

**Team Reflection:** Following the code reflection, students encounter a team reflection page with structured prompts about their collaborative process and their experience with the activity (see Figure 3b). These questions include "What was one thing you did well as a team?", "How did working in the journal help your team define your goals in this task?" and "What will you do differently next time to work better together?" These prompts encourage metacognitive discussion about the collaborative process itself, helping students identify both strengths and weaknesses in their communication and problem-solving strategies (Schürmann et al., 2025). By consistently and explicitly prompting students to discuss their teamwork, the notebook elevates the importance of the collaborative process to be on par with the technical solution. Meanwhile, it also provides a structured moment for students to voice concerns, celebrate successes, and strategize ways to improve their partnership in the next task, which develops crucial socio-emotional and communication skills that are central to engineering success (Dahm et al., 2009).

**Figure 3**

*Example of Collaborative Code (a) & Team Reflection Activities (b)*



Pick it, Score it! (Code Reflection)

**Review your Code:**
Reflect with your partner about the code you all created to complete the task. Take a sheetshot of your code that completed this task and annotate it, explaining what each part of your code does. Remember that the best code also has good documentation!

Project

Name Date Page

(a)

Pick it, Score it! (Team Reflection)

**Task Goal:**
Reflect with your partner on how you thought task 1 went. Work together to answer the following questions before moving on to the next section.

**Reflection Questions:**
What did you think of this task? Did you understand what you had to do in VEX?

How did working in the journal help us define our goals in this task?

Did you get stuck on this task? If so, can you explain which part you got stuck on? Were you able to overcome the problem?

Looking back at your Team Contract, which expectations did your team follow well? Which one could your team work on improving?

Project X

Name X Date X Page X

(b)

Together, these two reflection activities create a rhythm of technical work followed by collaborative sense-making, making reflection and iteration an integral part of the engineering process rather than an afterthought.

## Reflection, discussion, and next steps

Before developing the current version of the engineering notebook, our research team conducted a series of informal 30-minute interviews with middle school computer science teachers (*n*=3) and a VEX competition engineering notebook reviewer (*n*=1). These conversations helped us understand key differences between how engineering notebooks are used for *competition* versus *learning*. Specifically, we found that *competition notebooks* tend to include less scripting and fewer prompts, whereas *teacher-adapted notebooks* for classroom use are typically more structured and guided.

As traditional VEX engineering notebooks are relatively unstructured, for the first version of our notebook we adapted existing VEX materials to add a level of structure. We conducted a usability study at a computer science summer camp, which helped us arrive at a balance between open-ended exploration and structured guidance for the VEX challenge context. Insights from this study indicated that our previous iteration of the notebook did not adequately support productive collaboration or meaningful learning experiences. Instructors reported that there was insufficient prompting to sustain engagement and teamwork. Moreover, students tended to disregard documentation entirely unless it was directly connected to their active task or tied to an explicit incentive. We note that these findings emerged in an informal summer camp setting where students voluntarily participated; the balance of structure and guidance may need adjustment for formal classroom contexts where participation is mandatory and assessment stakes differ.

These insights directly informed the redesign of our engineering notebook present in this study. The new version serves as a design contribution that operationalizes theories of collaborative learning by embedding them into the curriculum itself. Rather than treating the notebook as a passive record, this version positions it as an active scaffold for fostering collaborative problem-solving. It makes collaboration unavoidable by assigning structured team roles, incorporating explicit reflection moments, and linking joint documentation to performance points in the VEX challenge.

As this is a work in progress, we aim to continue collaborating with teachers, students, and competition experts to refine the balance between structure and autonomy in future iterations. Our next phase involves testing this redesigned notebook in middle school computer science classrooms and afterschool programs, documenting challenges, and iterating based on user feedback.

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