Novel Engineering, K–8

An Integrated Approach to Engineering and Literacy

Elissa Milto, Merredith Portsmore, Jessica Watkins, Mary McCormick, and Morgan Hynes

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Preface

Novel Engineering is an innovative approach to including engineering in K–8 classrooms. As we've worked on Novel Engineering, we have been encouraged by the excitement that students and teachers have shown for their work during Novel Engineering units. One of the things we are excited about is that students have taken ownership of their learning and are able to navigate the steps of an engineering design process (EDP)—creating functional solutions to problems they have identified in texts. Of course, students would not be able to do this without the support and freedom given to them by their teachers. Many of the teachers with whom we've spoken have reflected that their own teaching has changed because they're better able to recognize what their students are thinking and understand their work.

In the United States, K–12 engineering education has gone from relative obscurity 20 years ago to part of the national science standards today. As it has evolved, we have seen that there are different ways of incorporating engineering into classrooms. Often, K–12 engineering activities are used as a vehicle to motivate or deliver science and math content, or they are stand-alone experiences for students to learn engineering with limited connections to science and math. In addition, they often do not emulate the experiences of real-world engineering.

Professional engineers have rich contexts in which they design. They have multiple stakeholders with different needs they must translate into design requirements; they have constraints on materials, time, or solution types they need to account for and balance; and they must address regulations and ethical issues. Professional engineers in these contexts are skilled at finding problems, identifying requirements, and balancing trade-offs. Often, when we transpose engineering into K–12 settings, some of the richness and wonderful messiness of real-world engineering is lost in activities that specify the problem and all the requirements for students. Engineering curricula for K–8 students are often

constrained both in problem definition and in material and solution diversity. These activities are great ways for students to engage in elements of engineering design and are often necessary with the realities of school, but they don't allow students to participate in the full design process.

Novel Engineering represents a significant shift in thinking about how engineering knowledge can codevelop with other disciplines, usually literacy but frequently social studies or another core subject. Novel Engineering works to replace real-world clients and contexts with those from literary texts to offer students opportunities to enter into engineering design practices that are messy, ill-defined, and without predetermined "correct" answers or paths through the EDP. Novel Engineering has shown a new model for engineering integration in which two disciplines are truly dependent on each other—and an approach where students are able to navigate the two successfully.

This book aims to support educators as they do Novel Engineering in their own classrooms and teacher educators as they work with preservice teachers. There are many teachers who have done Novel Engineering or have attended in-person professional development workshops, but the number of interested teachers and the range of locations make it impossible to meet with all teachers who would like to implement Novel Engineering with their students. It is our hope that through this book, we will be able to share Novel Engineering with a greater number of teachers.

This book will not only describe the Novel Engineering approach but also present case studies that allow readers to practice noticing student thinking and begin anticipating what students may do and say. In addition, this book will walk readers through the planning of a Novel Engineering unit so they can use the books they already include in their curriculum as part of a unit. By including Novel Engineering in the classroom, teachers give students the chance to engage in all steps of an EDP in a way that is personally meaningful.

Novel Engineering began in 2010 as a research project supported by the National Science Foundation. The first phase of the project was to understand what engineering looks like at the elementary school level. We examined what the engineering students were doing and what that looked like within an integrated context. As the research progressed, we also looked at Novel Engineering in middle schools and with students with language-based learning disabilities. Throughout the project, we collaborated with teachers to help us understand a teacher's point of view.

The Novel Engineering team had a broad understanding of the interaction among engineering and education research, educational tool development, and classroom implementation. The research team included individuals with back-

grounds in engineering, engineering education, psychology, literacy, science, education, and special education. Teachers participating in the research portion of the project functioned as partners, offering unique insights into the team's research and implementation. This diverse team allowed us to understand what was happening with students from a multitude of perspectives.

In addition to this background experience, the team worked directly with students while they were engineering. This allowed us to see what worked and what did not work and to better understand what students were capable of doing. This understanding of classroom dynamics and our partnerships with classroom teachers helped us develop not only the Novel Engineering approach but also the professional development experience.

Overview

Novel Engineering is an integrated approach to teaching engineering and literacy in elementary and middle school classrooms. Through this approach, students use literature as the basis for engineering design challenges, drawing information from the text to identify engineering problems, considering characters as clients, and using details from the story to impose constraints as they build functional solutions to the characters' problems.

For example, students who read the book *Danny the Champion of the World* by Roald Dahl identified Danny's father falling into a pit and getting stuck as a problem and then built and tested functional models to solve that problem (i.e., to get his father out of the pit) in a way that used resources appropriate to the story's setting. As students work on the text-based engineering projects, they also engage in productive and self-directed literacy practices. Novel Engineering tasks are truly interdisciplinary efforts in which students engage in both engineering and literacy activity. One teacher said, "That kids are using problem-solving skills based on basic engineering strategies, and it's an interdisciplinary unit combining science, math, and English language arts. … I think it's great—[it] gets kids to think in a different way." Since Novel Engineering began, we've been consistently excited by the work students have done and where our partnerships with teachers have led the project.

Novel Engineering continues to advance how students interpret classroom activities and how that interpretation influences the abilities and practices students leverage for learning. In Novel Engineering, we see students navigate classroom constraints, constraints presented by the text, and constraints of the real world. Engineering education literature often talks about students' limitations or inabilities. Novel Engineering's research findings add to the conversation about young students' sophisticated abilities and knowledge, and they push for more

work on unpacking the significance of context for students (Watkins, Spencer, and Hammer 2014).

Through our research, we've found that Novel Engineering benefits students in multiple ways. It provides a context for students to more deeply engage with assigned reading texts, whether they be in English language arts or history. The text serves as the basis for discourse, argumentation, and the sharing of ideas and thinking. In order to design for characters/clients, students need to make inferences and predictions based on what they've read that will influence their designs. There are many opportunities during a Novel Engineering unit for students to write, discuss what they have read, and argue for their point of view using evidence from the text.

In addition, the research conducted during the project has helped advance conceptions of what students are capable of with respect to engineering and how their capabilities are recognized in the classroom. Finally, Novel Engineering research has also advanced models and resources for preparing teachers to teach engineering, such as using videos of students engaged in engineering to develop teachers' abilities to notice when their students are showing emergent engineering skills.

Teachers have pointed out that Novel Engineering can reach students with different learning profiles—not just the "A students" who typically do well. For example, we've seen students with special needs excel at Novel Engineering; we've seen several instances of students with reading disabilities easily access a text supporting evidence for their design ideas. We've also seen students with significant organizational deficits manage the complex process of planning and realizing their ideas, which is often difficult to do when balancing multiple constraints and steps.

Wrap-Up

We know that readers will come to this book with a variety of backgrounds and experiences. It is for this reason that we imagine not everyone will read the book cover to cover and that readers may move between the chapters they feel best complement their experience levels with engineering and/or literacy. This book is broken into three sections: an overview of Novel Engineering's links to engineering and literacy, case studies, and logistical information for implementation.

We hope you enjoy reading this book and doing Novel Engineering with your students. We are continuously surprised by the amazing things we've seen students engineer and the discussions they've had about the books they read. We are sure you will be amazed by your students, as well.

Safety Considerations

Student safety is a primary consideration in all subjects, but it is an area of particular concern in science/engineering since students interact with tools and materials with which they are unfamiliar, posing additional safety risks. Teachers need to be sure that their rooms and other spaces are appropriate for the activities being conducted. That means that engineering controls such as proper ventilation, fire extinguishers, and eye wash stations are available and utilized properly. In addition, students should use sanitized indirectly vented chemical-splash goggles, safety glasses with side shields, nonlatex aprons, and vinyl gloves during all components of an investigation (i.e., setup, hands-on investigation, clean-up) in which they handle potentially harmful supplies, equipment, or chemicals. At a minimum, the eye protection provided to students must meet the ANSI/ISEA Z87.1 D3 standard.

Remember also to review and comply with all safety policies and procedures that have been established by your place of employment. Teachers must practice proper disposal of materials and proper maintenance of all equipment. The National Science Teaching Association (NSTA) maintains an excellent website (*www.nsta.org/safety*) that provides guidance for teachers at all levels. The site also has safety acknowledgment forms for each grade level. These forms are for students to review with their teachers and must be signed by parents/guardians.

Safety Notes are included in certain chapters to highlight specific safety concerns that might be associated with particular lessons. The safety precautions associated with each investigation are based in part on the use of the recommended materials and instructions, legal safety standards, and better professional safety practices. Selection of alternative materials or procedures for these investigations may jeopardize the level of safety and is therefore at the user's own risk.

Reference

Watkins, J., K. Spencer, and D. Hammer. 2014. Examining young students' problem scoping in engineering design. *Journal of Precollege Engineering Education Research* 4 (1): 43–53.

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Novel Engineering started as an idea and grew into an approach to learning engineering that has been more powerful than anyone could have imagined when we first started. We are very grateful for everyone who has helped advance the project to the state where it could become a book.

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- Our Novel Engineering Team: Chelsea Andrews, Susan Bitetti, Andy Braren, Sarah Coppola, Elise Deitrick, Tafari Duncan, Laura Fradin, Philip Gay, Daniel Haack, Caitlin Hall-Swan, Jeff Govoni, Aaron Johnson, Chip Jones, Emma Jones, Quinn Jones, Gard Ligonde, Dan Lu, Leonardo Madariaga, Kerrianne Marino, Bridget McCafferty, Lajja Mehta, Lisa Meyers, Matthew Mueller, Brian O'Connell, Victoria Portsmore, Alex Pugnali, Erin Riecker, Sarah Rosenberg, Jennifer Scinto, Jessica Scolnic, Ben Shapiro, Victoria Sims, Kathleen Spencer, Jessica Swenson, Nathan Tarrh, Jennifer Thomas, April Truong, Anne Vakkuzzi, Dan Wise, Anne Worrall, Megan Wyllie, Rafi Yagudin, and Lija Yang.
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About the Authors

Elissa Milto

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Elissa's background in teaching and special education led her to purse her second master's in engineering education and to become a core member of Tufts Center for Engineering Education and Outreach. As Director of Outreach, Elissa leads the center's work to provide schools, teachers, and other organizations with engineering design opportunities grounded in research. She leads the Student Teacher Outreach Mentorship Program (STOMP), a community-based outreach program; Design & Engineering Workshops; summer and afterschool programs for students and K–12 teachers; and she consults with local schools and international groups. Elissa is particularly interested in using open-ended, client-centered problems to bring engineering to elementary and middle school students and exploring ways that students with different learning styles and interests can become excited by and access engineering. Elissa has been leading the Novel Engineering project (*www.novelengineering.org*) since it began in 2010.

Merredith Portsmore

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Merredith Portsmore is the director of Tufts Center for Engineering Education and Outreach and a research assistant professor. She has the unique honor of being a "quadruple jumbo," having received her four degrees from Tufts University (BA in English, BS in mechanical engineering, MA in education, and PhD in engineering education). Merredith's research interests focus on how children engage in constructing solutions to engineering design problems, how teachers learn engineering in online environments, and how outreach programs affect K–12 students. Her outreach work focuses on creating resources for K–12 educators to support engineering education in the classrooms. She is the founder of STOMP, LEGOEngineering.com, and the online Teacher Engineering Education Program (*https://teep.tufts.edu*).

Jessica Watkins

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Jessica is an assistant professor of science education at Vanderbilt University. She received her PhD from Harvard University, studying the effects of undergraduate reformed physics courses. In her current research, she studies how K–16 students engage in science and engineering as disciplinary pursuits—that is, how they seek deeper understandings of the natural world and solutions to problems within it. She examines both moment-to-moment interactions and long-term dynamics of learners' engagement to understand how their disciplinary pursuits get started and progress over time. Grounding her research is the understanding that learners bring diverse, productive resources for science and that engineering and the role of educators is to help learners build on and refine these resources. Therefore, a second strand of her research is to design and study contexts in which teachers learn to attend to students' thinking in productive and expansive ways.

Mary McCormick

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Mary started her career in civil engineering working as a geotechnical engineer. When she returned to graduate school, her passion was ignited for engineering education. Mary received her PhD in STEM Education at Tufts, where she was a core member of the Novel Engineering research team. Her research focused on the dynamics of students' framing (sense of the task) during Novel Engineering activities. Mary currently works as a consultant at the Tufts Center for Engineering Education and Outreach, working on research, teaching, and writing projects.

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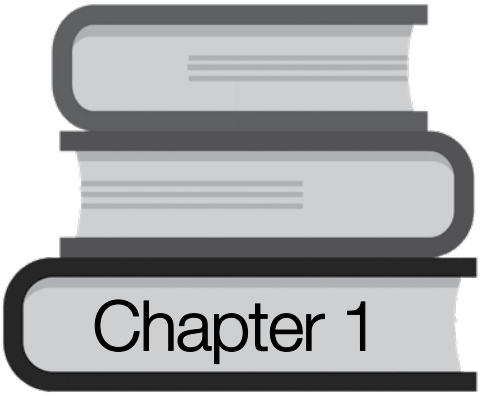
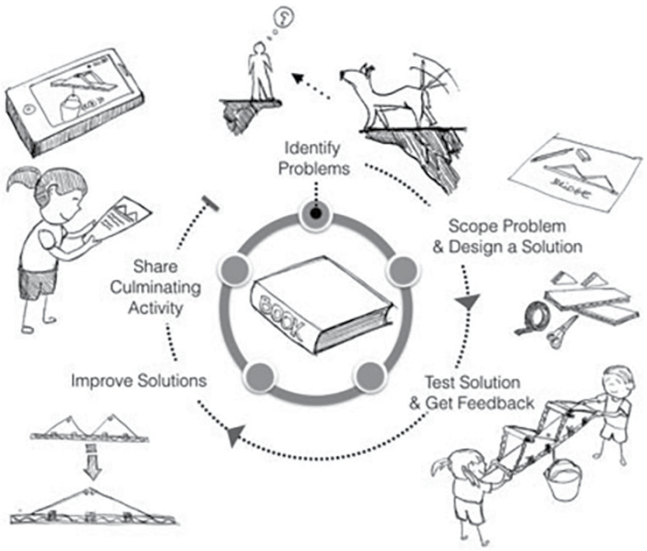
Morgan is an assistant professor in the School of Engineering Education at Purdue University and director of the For All: A Chance to Engineer (FACE) Lab research group at Purdue. In his research, Morgan explores the use of engineering to integrate academic subjects in K–12 classrooms. Specific research interests include design metacognition among learners of all ages; the knowledge base for teaching K–12 STEM through engineering; the relationships among the attitudes, beliefs, motivation, cognitive skills, and engineering skills of K–16 engineering learners; and the teaching of engineering.



Introduction to Novel Engineering

A lot of talk in education focuses on integration—combining subjects in meaningful ways to help students learn and see how knowledge and practices cross disciplinary boundaries. Novel Engineering, which follows the trajectory in Figure 1.1, can be taught as part of an English language arts (ELA) curriculum. It has also been implemented in other disciplines. Most of our research took place in ELA classes, so that is where most of the examples in this book take place. At first glance, engineering and ELA may seem like an unlikely pair for integration.

Figure 1.1: Novel Engineering design trajectory



On the one hand, there's engineering, which focuses on solving problems through iterative design. Engineering also pursues solutions to problems through careful identification of needs, requirements, and iterative prototyping, testing, and revision. Literacy, on the other hand, teaches students how to comprehend and interpret text to build understanding and how to engage in discussion, both oral and written, about text.

Novel Engineering gives students the opportunity to enter into engineering design through literature, offering authentic engineering projects that do not have predetermined, "correct" answers. While working on a Novel Engineering unit, students engage in engineering by drawing on their past experiences and understandings of the world and interact with classmates about what's happening in the book and what they have built. As students work on text-based engineering projects, they also engage in productive and self-directed literacy practices, including noting key details in text, making inferences, and writing lists and other notes that support the design process. Novel Engineering projects are therefore interdisciplinary efforts in which students gain experience in both disciplines.

One of the benefits of Novel Engineering is that it allows teachers to use some of their literacy blocks for projects since part of the students' time is used to interact with the text. Novel Engineering is similar to project-based learning in that curricular goals address more than one discipline, but it is different from project-based learning in that it has a specific focus on two disciplines.

This open-ended structure leads to solution diversity among groups within the same classroom. Although there is a basic framework for doing activities, there are not specific lesson plans or scripts. We've found, through our research and interactions with teachers, that by providing a framework for activities, teachers are able to develop their own content based on books that are already part of their curriculum. In fact, teachers with whom we have worked have told us how much they appreciate that Novel Engineering values their expertise and decision-making capabilities by not giving them highly structured lesson plans. It is for this reason that we have not included lesson plans in this book. However, we do include a sample lesson guide on the book's Extras page at *www.nsta.org/novelengineering*.

An Overview of Novel Engineering in the Classroom

The best way to begin this book is to sketch out what Novel Engineering can look like in a classroom. We've seen the book *Wonder* by R. J. Palacio used in several fifth-grade classrooms and are going to present a composite of these classrooms. Although there is variety among the classrooms and students, there are many similarities. *Wonder* is the story of Auggie, a fifth-grade boy who was born with a severe facial difference and is entering school for the first time. The book begins from his perspective and then switches to include the perspectives of the other characters. The teachers have several learning goals for students that include having students think intensely about the characters and the overarching themes of acceptance and friendship. This requires students to think about multiple characters' perspectives and make inferences about their thoughts and feelings. As the teachers read the book, they pause to give students time to discuss the problems that arose and to discuss, as engineers, how they might solve those problems.

As groups are engaged in discussion, the teacher walks around the room and listens to the discussions. One group wants to address the discomfort that the main character, Auggie, feels while eating in the school cafeteria. Due to his facial structure, Auggie is very messy when he eats and feels embarrassed. As two students, Samuel and Mateo, begin to consider solutions to this problem, it becomes evident that they are drawing on details of the story and making spontaneous inferences, all in service of understanding the design context. For example, they describe how they think Auggie feels, cite specific passages in the text, and infer the reason for those feelings—all of which help them empathize with Auggie about how it might feel to be bullied. They also generate a map of the cafeteria based on setting descriptions, consider the social landscape of an elementary school, and come up with a list of foods that may be easier for him to eat in public.

The following is an excerpt of a conversation between the two students. The conversations throughout this book are numbered so that if teachers are discussing them in groups, they can use the numbers to refer to students' statements.

1. **Samuel:** He doesn't like to eat with everyone.
2. **Mateo:** He could just not eat in the cafeteria, maybe in a classroom with a teacher?
3. **Samuel:** No, he is in school to be with the other kids. We need to make something so he can eat in the cafeteria. What can we ...
4. **Mateo:** He'll be afraid people will look at him.

5. **Samuel:** We can make something that will let him eat and make it less messy.
6. **Mateo:** Okay. How can it be less messy so the food doesn't fall out? Maybe something that catches food but blocks his mouth?
7. **Samuel:** It can be like a fork but hides his mouth.

The following day, the group begins building a device that will help Auggie eat with less mess. As in most Novel Engineering classrooms, the students are provided with a list of available teacher-supplied materials when they begin to plan, which typically include a variety of cheap and recyclable materials such as tape, paper clips, cardboard, string, and cloth. A suggested list of materials is included in Appendix A (p. 223).

Samuel and Mateo propose to test their device using a range of foods, such as a yogurt, apples, and cheese. As they test their device, they are reminded by the teacher to record their findings in an engineering journal so they can share findings with the class and make changes, if needed, the following day. While sharing their findings with their classmates, the students describe their design choices and rationale, the way they tested their design, and how they intend to improve it. Samuel and Mateo want it to look as much like a traditional fork as possible so Auggie will not feel self-conscious. With that in mind, they include a small guard that helps keep food in his mouth.

In many Novel Engineering units, a writing assignment is included as part of a final culminating activity. In Samuel and Mateo's class, students have been instructed to write a journal entry as Auggie, describing how the engineering solution helped him overcome the problem. The pair of boys write about how Auggie felt less fear during lunchtime and is now able to talk to a friend at the lunch table. The students make projections about how their device would help Auggie gain confidence, which in turn would affect his life. In this example, Samuel and Mateo organically worked through an engineering design process (EDP) without being required to follow the process as a checklist; rather, they were allowed to move naturally through the steps. We will discuss the EDP used in Novel Engineering in the next two chapters.

After their first Novel Engineering experience, teachers often say that their students exceeded their expectations. In the previous example, Samuel and Mateo thought deeply about how Auggie might feel in different situations, such as eating in a school cafeteria or meeting new people. They also made inferences from the text and used their knowledge of the characters to project how different scenarios might play out. The teacher spoke with students as they worked, which

provided a strong understanding of what their ideas were around the text, their design choices, and their construction of the final design.

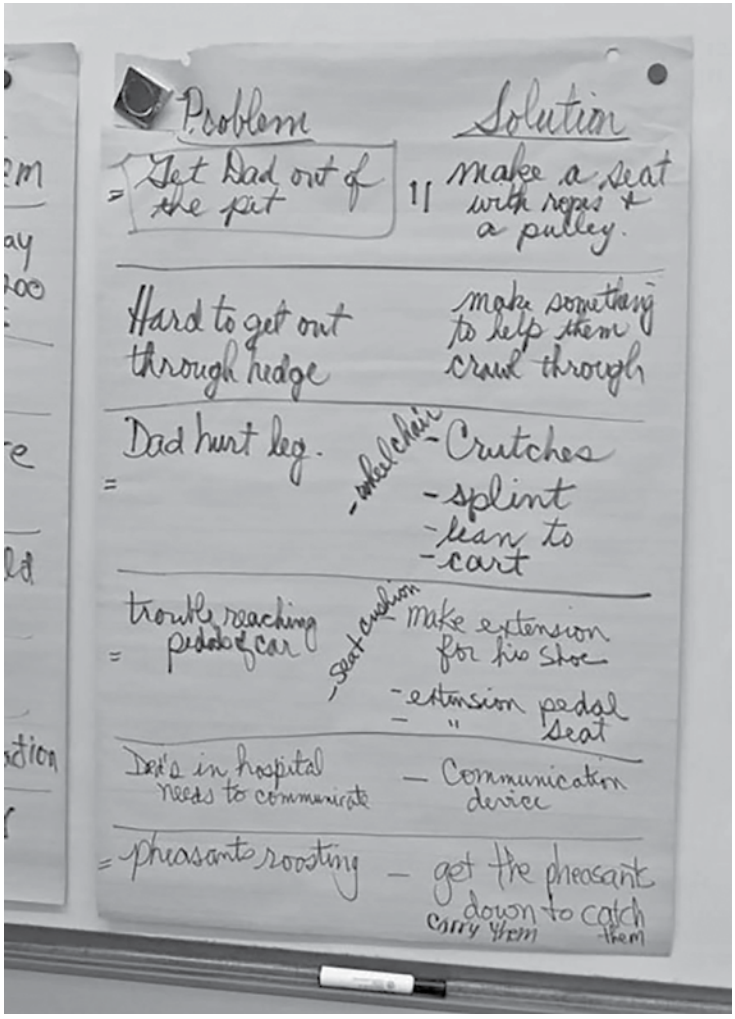
In addition to meeting ELA goals, students worked collaboratively with partners or group members, communicating their ideas and supporting one another in the process. Most surprising to teachers, however, is the way their students act like young engineers. When engaged with the *Wonder* unit, students think critically about their designs, present evidence to support their design decisions, test their ideas, evaluate those ideas, and then iterate to improve their designs.

This example mirrors the experiences of hundreds of teachers with whom we have worked. Teachers consistently indicate that the integration of engineering and literacy is synergistic and powerful. Stories provide complex settings (engineering design contexts) and characters (clients) with real problems and needs, and the students' desire to help those characters by designing functional engineering solutions motivates a deeper reading and understanding of the texts. Most important, students become excited about what they are reading, writing, designing, and building! This excitement in turn helps them make strides in both engineering and literacy, as well as in their abilities to work together, think creatively and analytically, and communicate their ideas.

Novel Engineering provides a structure for students to do engineering while simultaneously working in the content areas. Books, short stories, and nonfiction texts can offer a broad context for engineering design problems that are complete with built-in constraints and criteria. In Novel Engineering, students read and identify engineering problems in the books or other texts, consider characters as clients, and then use details from the story to build functional solutions to address the characters' problems. An example of student-generated problems based on students' work with the book *Danny the Champion of the World* can be seen in Figure 1.2 (p. 8).

Books can range from picture books appropriate for kindergarteners to more complex novels for older students (see Table 1.1, p. 9). Although we will talk about the literacy and engineering portions of Novel Engineering as distinct tasks, students actually see them as part of the same task and bounce back and forth between them minute by minute. Including a hands-on piece is more time consuming, but one of the benefits of Novel Engineering is that it allows teachers to use some of their ELA blocks for these projects and provide time for students to interact with the text.

Figure 1.2: List of student-generated problems from *Danny the Champion of the World* by Roald Dahl



Guiding Principles of Novel Engineering

From our work at Tufts University, we've seen that students are capable of jumping into engineering projects with little guidance and that teachers can use Novel Engineering as an entry point to meet classroom goals. We've also seen that Novel Engineering provides teachers with a concrete way to attend to and respond to student thinking. These observations—along with our belief in the abilities of students and teachers—helped us formulate our guiding principles.

Table 1.1: Sample books used as part of Novel Engineering units

Title and Author	Grade Level	Lexile Level	Problems Identified by Students	Solutions Designed by Students
The Snowy Day by Ezra Jack Keats	K–2	AD500L	Keeping Peter's snowball longer	• Insulated snowball savers • Portable insulated snowball saver
Tales of a Fourth Grade Nothing by Judy Blume	3–5	470L	• Protecting Peter's pet turtle from his brother, Fudge • Preventing Fudge from getting out of his crib	• A turtle cage that prevents Fudge from getting to Peter's pet • An alarm system attached to Fudge's crib that will ring a bell when he tries to escape
A Long Walk to Water by Linda Sue Park	6–8	720L	• Nya must carry large amounts of water far distances every day • Thorns cut Nya's feet as she walks through the desert transporting the water	• A sled that can carry the water and move over rocky terrain • Shoes made of cheap materials

Novel Engineering is motivated by two guiding principles:

1. Students of all ages are capable of engineering, and their ideas can be used to inform their designs.
2. Teachers are capable of making decisions about their classrooms and their students' learning.

Rather than working from a deficit model with students, we value pre-existing student knowledge and feel that students can build on what they already know about the world as they design. Regarding teachers, the core belief that they need to be given flexibility and opportunities to make decisions about their own classrooms and students' learning means we see teachers as capable professionals who do not need "teacher-proof" curricula and should be empowered to design learning environments. Along with this flexibility is the opportunity to listen to and respond to students' ideas. When given this freedom, teachers are able to make judgments about their students' learning and decide how best to support their work.

This flexibility for both students and teachers means Novel Engineering is an open-ended approach in both how it is presented to students and how students engage in solving problems. This open-endedness means the engineering closely mirrors the real-world EDP, which is inherently messy. It also means that student engagement is elevated because students find and solve problems that are interesting to them and match their individual skills and interests. A teacher may use the same book two years in a row, but the discussions and student solutions may be very different from year to year. Although there is a trajectory that all Novel Engineering units follow (see Figure 1.1, p. 3), this serves as a path for students rather than a checklist of steps. We will talk more about the Novel Engineering trajectory in the next chapter.

Building off the first principle, students' ideas play an important role in Novel Engineering, and classroom culture should be crafted so students are comfortable sharing and acting on their ideas. We are not saying that you should let your students do whatever they want. Rather, the insight gained from understanding students' ideas gives you information about how to support students and when you can push back on their ideas. For example, there will be times when students plan to make something that is not functional or mechanically possible, such as a shrink ray, or when they want to build something that is more complicated than they have time to build.

Understanding what students are thinking will help teachers respond in a way that builds on and supports students' ideas. Rather than approaching students' work and immediately trying to improve what they are doing, teachers should take time to understand what students are thinking and why they made certain design decisions. This will help teachers respond appropriately so they can meet students where they are. Being a responsive facilitator means guiding students by asking questions and making observations so they can design realistic solutions given the available materials and time constraints.

As is evident in the dialogue between Samuel and Mateo, students are able to participate in complex discussions while navigating the EDP and thinking about the book they are reading. Teachers are often surprised and impressed with what their students can do, and students are excited to engage in hands-on, engineering design activities that do not have predetermined answers.

How Did Novel Engineering Begin?

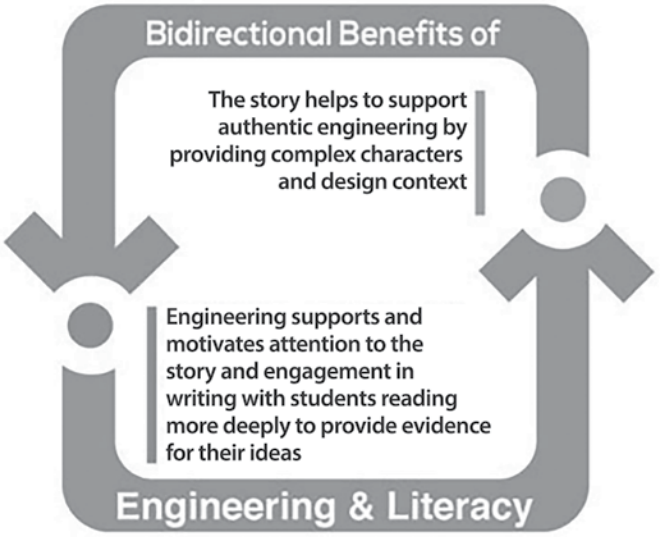
When we started Novel Engineering, we looked at existing research from engineering, literacy, and teacher education to build on an existing concept from a local nonprofit partner, Bill Wolfson, who was using children's books to present engineering to young children. In looking at this research, we found an argument that demonstrated there was potential for design and engineering to facilitate learning in other disciplines (e.g., Kolodner 2002; Wendell and Rogers 2013) and that students' past experiences are rich resources for design projects (e.g., Portsmore 2013). This led us to think about how closely the engineering and literacy in Novel Engineering needed to be linked and how both disciplines needed to have equal value.

The Novel Engineering project began in 2010 with an interdisciplinary team of researchers and educators in engineering, literacy, education, and psychology. Our team spent the first five years of the project working with teachers and conducting research in their classrooms in rural, urban, and suburban schools. Over the course of the research, we worked with more than 500 students and filmed them as they engineered solutions to problems encountered by characters in the books they read. Research revealed what was happening as students engaged in this integrated setting and how teachers interacted with and supported their students. We documented how young students first approached engineering, how novice engineers navigated open-ended engineering design tasks, and how the integrated context influenced students' design methods (McCormick and Hammer 2016; Watkins, Spencer, and Hammer 2014). We also looked at how teachers recognize and respond to students' engineering ideas (Johnson, Wendell, and Watkins 2017; McCormick, Wendell, and O'Connell 2014; Wendell 2014).

Bidirectional Benefits

Constraints on teachers are growing and the freedom to choose what happens in the classroom is shrinking, so it may seem crazy to think of adding yet another initiative into the classroom. New initiatives must fulfill multiple functions. In our research classrooms, we saw that Novel Engineering was able to bridge several disciplines while also meeting educational standards, classroom goals, and individual goals. (In Chapters 2 and 3, we touch on how Novel Engineering aligns with *Next Generation Science Standards* and *Common Core State Standards*.) Figure 1.3 (p. 12) shows some of the benefits we've seen for students in implementing Novel Engineering in classrooms. In practice, we've found that engineering and literacy are mutually beneficial—with the text giving the engineering context and authenticity and the engineering supporting students' attention and engagement.

Figure 1.3: Bidirectional benefits of Novel Engineering



A New Kind of Resource for Teachers in Engineering and Literacy

There are many engineering curricula for young students in which students design solutions for problems rather than clients. For example, students may be tasked with building a tower of marshmallows and uncooked spaghetti. This activity may help students work on collaboration and testing skills, but it does not present students with a client or give them a context to consider as they design. With such structured tasks, there is very little solution diversity since students are working with the same materials and have been given the same constraints and criteria. Additionally, real-world engineering problems are not as neatly packaged as this. Professional engineers must sift through lots of information to figure out design criteria and constraints they need to address as they plan a design. Novel Engineering is unique in that students get to experience the messiness of engineering and have the chance to scope the problem and empathize with their clients as part of the design process.

Our research has shown that students are able to navigate the EDP without explicit directions. As we noted previously in this chapter, most elementary engineering experiences provide students with well-defined problems and a structured path through the EDP. This obviously results in all students arriving at similar solutions. In Novel Engineering, students define the engineering prob-

lems themselves as they design functional solutions based on their own ideas. As they work, they make design decisions and refine their ideas based on evidence from the book, feedback from tests, and feedback from peers. In addition to meeting standards and the goals of the classroom, Novel Engineering allows students to take ownership of a project and tackle challenging problems while working collaboratively (see Figure 1.4). This is in line with what has been outlined by the National Academy of Engineering and National Research Council (2009); it's important for all K–12 students—not just those taking engineering courses—to develop engineering habits of mind.

For the literacy aspect of Novel Engineering, we have found that students productively engage with text in a variety of ways that align with *Common Core State Standards*. They take the perspective of characters and note relevant aspects of the physical setting as they plan and evaluate their designs. Spontaneous discussions emerge as students wrestle with unfamiliar concepts and vocabulary in an effort to better inform their designs. These discussions lead to students constructing an informed interpretation of the text.

Figure 1.4: Students working on a communication system for the main character in *The City of Ember* by Jeanne DuPrau

Designed for Educators

Novel Engineering is designed to be a flexible approach for teachers. Though we recommend a semistructured flow of activities, there is no one "correct" way to do Novel Engineering, nor is there a set curriculum for teachers to follow. Novel Engineering works with most trade books and allows students to work on academic objectives identified by each teacher or school. Many teachers have found that Novel Engineering meets their academic objectives in a range of subject areas, from ELA to social studies to mathematics. Teachers have also said the Novel Engineering approach builds on their experiences and expertise rather than having them learn a completely new curriculum that does not necessarily work with the other curricula and structures that are already in place in their classrooms. Novel Engineering works well with existing curricula and plans since teachers get to choose the text and direction of student work; they can use texts students already know and are comfortable with rather than unfamiliar books from an assigned list.

Teachers have also noted that Novel Engineering helps them develop a classroom culture that includes productive class discussions and peer critique. Even though Novel Engineering requires teachers to have a basic understanding of engineering and the EDP, it does not require them to have a formal engineering background. Instead, it builds on their unique disciplinary backgrounds and classroom experiences. When working directly with teachers, we have them do a Novel Engineering unit to get a feel for the process their students will be undertaking. This book, then, is designed to help teachers gain familiarity with key aspects of engineering and help structure the process of presenting engineering to students.

Finally, Novel Engineering helps teachers look at their students in new ways. Many teachers have said that it helped them step back and notice what their students were doing and thinking. This more critical look at student thinking helps teachers understand why students make certain design decisions (related to both the text and the mechanics of the design) and why they have certain interpretations of the text. This more informed view of student thinking enables teachers to respond more appropriately to what students are doing and helps them guide their next moves. Teachers have also said that Novel Engineering helped them notice new things about their students, such as strengths or places for improvement, that did not come out in other classroom activities.

Overview of This Book

We wrote this book to share what we have learned from doing Novel Engineering in more than 100 classes. This book will walk teachers and teacher educators through the Novel Engineering approach, show concrete examples of what students may say and do, and prepare teachers to implement the approach in their classrooms. Although it's a simple concept, Novel Engineering requires teachers to anticipate what their students may do (say, think, and design), listen to their ideas, and set up structures that support students' work while meeting academic objectives.

This book is divided into three sections. Section I describes the Novel Engineering approach in more detail, what engineering looks like in young students, and how literacy and engineering support each other in project-based work. Section II consists of case studies that prepare you to lead a Novel Engineering unit and support your students as they practice being engineers. To this end, you will learn to recognize students' engineering skills and respond to student thinking. Section III includes practical elements that will be helpful in planning and implementing a Novel Engineering unit.

You do not need to read this book straight through; rather, you can jump from chapter to chapter. We definitely recommend starting with Chapters 1, 2, 3, and at least two of the case studies. After that, browse the sections you feel are most relevant to your specific classroom needs. We believe this book will help you respond to your students' work and allow them to have an authentic engineering experience as they play around in the true messiness of engineering. It will also provide students with an opportunity to be creative and follow their own ideas, taking ownership of their learning.

Visit
www.novelengineering.org
for additional Novel Engineering resources!

References

Johnson, A. W., K. B. Wendell, and J. Watkins. 2017. Examining experienced teachers' noticing of and responses to students' engineering. *Journal of Pre-College Engineering Education Research (J-PEER)* 7 (1): 25–35.

Kolodner, J. 2002. Facilitating of learning design practices: Lessons learned from an inquiry into science. *Journal of Industrial Teacher Education* 39 (3): 9–40.

McCormick, M. E., and D. Hammer. 2016. Stable beginnings in engineering design. *Journal of Pre-College Engineering Education Research (J-PEER)* 6 (1): 45–54.

McCormick, M., K. B. Wendell, and B. P. O'Connell. 2014. Student videos as a tool for elementary teacher development in teaching engineering: What do teachers notice? (Research to practice). *Proceedings of the 2014 ASEE Annual Conference & Exposition*, Indianapolis, Indiana.

National Academy of Engineering and National Research Council. 2009. *Engineering in K–12 education: Understanding the status and improving the prospects*. Washington, DC: National Academies Press.

Portsmore, M. 2013. Exploring first grade students' drawing and artifact construction during an engineering design problem. In *"Show me what you know": Exploring representations across STEM disciplines*, ed. B. M. Brizuela and B. E. Gravel, 208–222. New York: Teachers College Press.

Watkins, J., K. Spencer, and D. Hammer. 2014. Examining young students' problem scoping in engineering design. *Journal of Pre-College Engineering Education Research (J-PEER)* 4 (1): 43–53.

Wendell, K. B. 2014. Design practices of preservice elementary teachers in an integrated engineering and literature experience. *Journal of Pre-College Engineering Education Research* 4 (2): 29–46.

Wendell, K. B., and C. Rogers. 2013. Engineering design-based science, science content performance, and science attitudes in elementary school. *Journal of Engineering Education* 102 (4): 513–540.

Websites

Common Core State Standards: *www.corestandards.org*
National Science Foundation: *www.nsf.org*
Next Generation Science Standards: *www.nextgenscience.org*
Novel Engineering: *www.novelengineering.org*

Book Resources

The City of Ember; DuPrau, J.; Age Range: 5–12; Lexile Level: GN520L
Danny the Champion of the World; Dahl, R.; Age Range: 8–12; Lexile Level: 770L
Wonder; Palacio, R. J.; Age Range: 8–12, Lexile Level: 790L

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Novel Engineering, K–8

An Integrated Approach to Engineering and Literacy

With the Novel Engineering approach, "students become excited about what they are reading, writing, designing, and building! This excitement in turn helps them make strides in engineering and literacy, as well as in their abilities to work together, think creatively and analytically, and communicate their ideas."

—from Chapter 1 of *Novel Engineering, K–8*

This book will both introduce your students to an exciting integrated curriculum and support you as you use it in your own elementary or middle school classroom.

Novel Engineering, K–8 shows how your students can work through engineering design challenges inspired by a broad range of literature—novels and short stories, biographies and histories, or even picture books. By way of introduction, the book offers clear conceptual background and practical advice on how the approach works: Your students pull information from literature to identify a problem. Then, using details from the story or text, they go through an engineering design process to develop functional solutions for their "clients"—the book's characters.

To support your efforts and bring the concept to life, the book gives you five in-depth case studies featuring the use of novels, a biography, and a nonfiction historical text. In addition to demonstrating what a Novel Engineering project looks like in an actual classroom, the case studies give you practice in thinking about what your students' work might look like and how you would respond. One case describes a class in which students help the shipwrecked Swiss Family Robinson build a shelter to keep them cool under the hot sun. Another tells of students who design a hearing aid for the main character in *El Deafo*—and then style it as a fashion accessory.

You'll see that the books used in the case studies are just suggestions. You don't have to adopt texts outside your existing English language arts or social studies curriculum. You also don't have to buy a specific building-materials kit. You just have to embrace the idea that literacy and engineering can support each other in your classroom—and then watch the excitement build.

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Grades K–8

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