**Appendix A: Vignettes Used in Part 1 of Instructional Sequence (Elementary Version)**

Consider the following scenarios of classroom instruction. For each one, indicate how much you think the scenario represents a *science activity* and how much it represents an *engineering activity* (it could be both or neither!). For this task, don’t worry about whether the lesson is “good” or “bad.” Instead, just focus on whether it seems to be *science* or *engineering*. Be prepared to give your reasoning for each scenario.

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| **Scenario 1:** Ms. Blake is leading her group of 2nd graders in an investigation of soap bubbles. The question guiding the investigation is: *What mixture of soap and water allows us to create the biggest bubbles*? Ms. Blake begins with a whole-group discussion with students about how they could set up an investigation that would allow them to answer this question. During that discussion, she guides students to develop a consistent and detailed procedure for making bubbles and measuring their size. She lets students decide which soap mixtures they want to test and how they want to make those mixtures. In small groups, students then work with their materials and collect and record their data. Each group is tasked with making sense of their results and drawing an overall conclusion. After the activity, the whole class comes together to compare their findings and return to the guiding question. Ms. Blake helps students talk through their different findings and come to a consensus on the answer to the question. |

To what extent do you think is this an example of a *science* *activity*? Use the scale below.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| This is clearly **not** a science activity. |  | This is somewhat a science activity. |  | This clearly **is** a science activity. |
| 1 | 2 | 3 | 4 | 5 |

Explain your rating:

To what extent do you think is this an example of an *engineering activity*? Use the scale below.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| This is clearly **not** an engineering activity. |  | This is somewhat an engineering activity. |  | This clearly **is** an engineering activity. |
| 1 | 2 | 3 | 4 | 5 |

Explain your rating:

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| **Scenario 2:** For the past few weeks, 3rd-grade students in Mrs. West’s class have been learning about ecosystems, including how different parts of an ecosystem interact with one another and how individual organisms survive in ecosystems. Mrs. West then presents students with the task of figuring out how to best set up an aquarium in the classroom. She provides students with a list of different organisms that students might put in the aquarium, along with some of the different pieces of equipment that students might use (thermometers and pumps as well as cosmetic structures like castles). In small groups, students research the different organisms to determine what needs each of them has. Groups also research the aquarium equipment to find out the uses for each of them. The groups then share what they learn with the class. Afterward, each group develops a plan for how they think the aquarium should be set up, and they present those plans to the rest of the class. Mrs. West guides a group discussion of the different ideas and helps the class come to a consensus on which plan the students think will work best. The class then works together to implement that plan in the classroom. |

To what extent do you think is this an example of a *science* *activity*? Use the scale below.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| This is clearly **not** a science activity. |  | This is somewhat a science activity. |  | This clearly **is** a science activity. |
| 1 | 2 | 3 | 4 | 5 |

Explain your rating:

To what extent do you think is this an example of an *engineering activity*? Use the scale below.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| This is clearly **not** an engineering activity. |  | This is somewhat an engineering activity. |  | This clearly **is** an engineering activity. |
| 1 | 2 | 3 | 4 | 5 |

Explain your rating:

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| **Scenario 3:** Mr. Green’s 5th-grade class is learning about how water shapes landscapes over time. He begins by taking the class outside to observe the stream that runs near the back of the school. Students record their observations and make speculations about how the stream affects the land (rock and soil) around it and why the stream looks the way that it does. Back in the classroom, Mr. Green sets up stream tables for students to explore. The stream tables are set to different inclines and include different types of solid materials, from fine-grain sand to coarse gravel. After Mr. Green demonstrates how to use a stream table, he tasks students with investigating how water interacts differently with each material and how the incline of the stream affects those interactions. Students work in small groups with the stream tables, record their observations, and use those observations to draw conclusions. As a whole class, Mr. Green has student groups share their conclusions to reach a group consensus about the ways that water interacts with the materials. He then tasks each group with using what they learned to create an explanation for why the stream behind the school looks the way that it does and how they expect the stream to change over time. |

To what extent do you think is this an example of a *science* *activity*? Use the scale below.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| This is clearly **not** a science activity. |  | This is somewhat a science activity. |  | This clearly **is** a science activity. |
| 1 | 2 | 3 | 4 | 5 |

Explain your rating:

To what extent do you think is this an example of an *engineering activity*? Use the scale below.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| This is clearly **not** an engineering activity. |  | This is somewhat an engineering activity. |  | This clearly **is** an engineering activity. |
| 1 | 2 | 3 | 4 | 5 |

Explain your rating:

**Appendix B: An Example Engineering Story**

**Armin: Chemical Engineering in the Energy Industry**

Armin is a chemical engineer in the research and innovation department of a large energy resources company. There are teams in his department who work on research and development (R&D) projects, but Armin is actually a part of what is called “Business Unit Support,” which works on different kinds of things. He essentially serves as an expert consultant, most often for oil refineries in the United States and the UK. Armin has a PhD in Chemical Engineering, and he has extensive expertise that he uses to help refineries work through various problems and challenges that they encounter.

[Refineries] will have issues, loss of profit situations where, for example, their unit is down for a week and if they can’t get it up, they’ll obviously be losing money. So they reach out to us, they say ‘we have this problem, we need some research support,’ or ‘we need some ideas on how we can deal with these problems and solve them.’ We basically consult and tell them to test this and that, talk to some vendors, collect information, maybe do some tests in the lab, and eventually give them some recommendations.

Those consulting projects can vary in size and scope; some can be resolved relatively quickly, but others might run for several years. One of the bigger projects that Armin is working on involves a refinery that is trying to take a bio-based waste and turn it into fuel that could replace conventional petroleum-based fuels. The refinery has a pretty large incentive to make it work because there are lots of subsidies and credits that governments will give for biofuel production. But it turns out that it’s not at all easy for the refinery to handle the new material, and the system has to be modified and re-designed to accommodate it.

Because this [bio-based waste] has different properties than petroleum, that is creating a lot of problems. We are helping them, we are doing a lot of tests in the lab to figure out where those problems are coming from and how to solve them.

They’ve been working on those problems for several years already, and they’ll likely keep working on them for several more. In this case, the economic incentive is powerful enough to keep pushing forward, even though progress is slow and certainly not guaranteed. In other cases, though, if progress doesn’t get made relatively quickly, the customer might decide that it’s not worth the monetary investment to keep trying. R&D projects often work that way; most are very speculative in that they might lead to fantastic results but more often won’t lead anywhere at all. The company wants to encourage R&D departments to pursue promising leads, but all R&D projects require resources (time and money). Therefore, most projects are ended within a couple of months unless they show a very high likelihood of success.

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| ***1. Notice how the engineering projects that occur within this company are very sensitive to economic considerations. That, of course, is true of pretty much all engineering work that is done in private industry. How do those economic considerations affect the kinds of projects that engineers pursue (or not pursue)? How does that differ from the ways that scientists (who don’t work in private industry) choose which projects to pursue?*** |

**Collaborations**

When Armin works with a refinery, he typically works with process engineers and chemists at that refinery who are extremely knowledgeable about the specific systems with which they work. In fact, there’s probably nobody who knows more about those systems! So if they have all that knowledge and expertise, why would they need to bring in a consultant? What kinds of expertise does someone like Armin bring?

You have access to some technical knowledge that they don’t have access to. You have technical knowledge because you’ve done some graduate work, you’ve done some research, but also you have access to all of these technical reports and R&D reports and research notes. Those are things within our company. In addition, you have access to the research literature, and because of your training as a PhD, you know how to refine and find the good stuff. So they rely on you to find good material.

Armin learns as much as he can from the engineers and chemists at the refinery and then uses his expertise to develop possible courses of action that those engineers and chemists would not have found on their own. The “product” that he creates depends on the situation, but in general, it comes in the form of “actionable information”: a recommendation for what the refinery ought to do. Of course, the refinery might not necessarily take that recommendation.

If I cannot convince the refinery that this actionable information is accurate enough and is going to help them, they’re not going to act on it. And if they don’t act on it, then they’re not buying my product.

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| ***2. Engineering projects are, at their core, about developing technological systems, and the work that Armin does is no exception. Many people, however, believe that engineers are primarily “makers” of physical things. Even though the “products” that Armin creates are not physical objects, in what ways are they nevertheless engineering products?*** |

What, then, does it take to convince the relevant people that his ideas are worthy of action?

You have to be really, really patient. When you come up with an idea . . . for example, I have this idea for a solution for this problem that we’re having, and I’m pretty confident that it will solve at least 80 or 90 percent of the problem. But you have to make sure that you communicate that with everybody and convince everybody, and that can become quite frustrating. Obviously, they’re going to spend a lot of money implementing your idea, so it’s good that they’re looking for something convincing. Hopefully they don’t do something without getting convinced! But from your perspective, you have to be patient and check the boxes and make sure everyone knows what you mean.

First and foremost, you have to convince yourself that your data is right. We look at the data from the refinery, we analyze it, we look for patterns, we look at data from the lab and try to mimic those results on a small scale—and then we do some calculations to see how that would play out on a larger scale.

Here’s the most important part. It does not matter if your product is the best product. It does not matter if what you are saying is going to help the refinery, unless your customer trusts you. All the technicalities that you learn in school and training and education is great, but the most important thing . . . it’s like you look at a screw and you look at a screwdriver and you can’t physically use the screwdriver to turn the screw. That trust between you and the customer is the physical strength that allows you to pick up the screwdriver and turn the screw. If it’s missing, it’s not going to happen.

So convincing the relevant people that your idea makes sense requires a lot more than technical skills. Armin has found himself constantly developing his ability to effectively communicate his ideas to people with all kinds of different backgrounds. The way you present your ideas to an engineer is very different from how you would present them to someone without any technical training:

So if you’re talking to someone on the leadership team, they’re not necessarily a trained engineer or chemist, they probably have an MBA or something like that. They probably don’t understand anything technical. Maybe some, but if you start talking about engineering or chemistry or research things, you’ll go over their heads very quickly . . . during your education and training in school, I think that’s the one thing that’s missing.

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| ***3. Engineering is a technical field and engineers must therefore develop a range of technical knowledge and skills. But notice how Armin also needs interpersonal skills to do his job well because he has to ultimately convince other people that his ideas make sense! If Armin lacked those interpersonal skills, what problems would that cause?*** |

**Engineering or Science?**

The technology industry brings together people from a variety of different backgrounds. Many of the people with whom Armin works were trained as engineers, but others were trained in the sciences. When those people work on collaborative projects, in what sense are they doing engineering, and in what sense are they doing science? In the work that Armin does, he often sees himself switching between a scientific mode of thinking and an engineering mode of thinking. When he is running experiments in the lab and making fundamental inquiries into the materials and systems that are involved in his projects, he thinks of himself as doing science. When he deals with the practical applications of those ideas to the specific technological problem he is trying to solve, he thinks of himself as doing engineering. The way he thinks about this is influenced by his experience as a graduate student.

In grad school, in my PhD, the majority of my focus was science, even though I’m a chemical engineer by training and my degree is in chemical engineering. It was mostly on science because when you’re trying to do research, in graduate school, research is very much like R&D in a company. So, you are trying to push the boundaries of science and engineering. In chemical engineering, more often than not, it’s science related. So, you are looking at a new material and seeing if it helps for your process, or looking at the chemistry, the physics, the mathematics of something.

The kind of science that Armin describes here is most often referred to as “engineering science.” Like the natural sciences, engineering science aims to generate new knowledge about the world. Importantly, though, the kind of knowledge being developed is closely tied to technological systems. When Armin researches the properties of some material, that material is targeted because of its clear relevance to a technological system, and the applicability of any new knowledge is always on his mind. Nevertheless, engineering science represents a distinct mode of thinking from more traditional “engineering.” Because Armin’s experience as a PhD student was primarily one of doing engineering science, he found that he had to recover some different ways of thinking that he hadn’t used for some time.

When I transitioned to industry, something that hit me most was that now I have to use all that engineering knowledge that I gained during my masters and bachelors, which was like six years ago. I need to make use of that. I see engineering graphs all over the place and I have to understand what that is to know what people are even talking about. A lot of engineering terms, a lot of things I hadn’t visited for a long time, I had to go back and revisit. At the same time, on the science side of things, it’s similar to what I did in graduate school.

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| ***4. Science and engineering are clearly related to one another, but they also have some important differences. Drawing examples from Armin’s work, what do you see as some of the most significant differences between science and engineering? In terms of Armin’s work, what do you see as some of the most significant connections between the two?*** |

**Appendix C: Transcript of Whole-Class Discussion During Part 1**

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| **Context:** In a secondary science methods course, the students have just finished discussing the three teaching scenarios in their small groups. They have come to a consensus on ratings and reasons. The teacher has been circulating among the groups to help them clarify their thinking but hasn’t pushed students toward any particular ideas at this point. The time stamp indicates that about 10 minutes have elapsed since students began working in small groups on the scenarios. |
| [9:40]Teacher | I was listening carefully to your conversations, and it seems like some consensus has been reached, although I’m guessing that between our groups, I don’t think we landed in exactly the same place. So let’s start with scenario number one. So, ratings of science—call them out. |
| Student | Well, I wanted a four, but he wanted a three. |
| Student | Wait til you hear the engineering. |
| Teacher | Well, okay, what did you think about the engineering? This group thought a four. |
| Student | I say five; he says two. |
| Student | Did you guys ever agree? |
| Student | On the first two, no. On the last two, yes. |
| [10:35]Teacher | So let’s address this, and I know that this group did wrestle for a bit with the engineering-ness of this scenario. Seems like we were all feeling like there was science here. But in terms of engineering land, it was a bit of a tougher thing to figure out. What’s some of our rationales for the ratings? |
| Student | So I gave this a five for engineering because they were collecting data to optimize the ball launcher. |
| Student | I gave it a two because even though they’re running various trials with the ball launcher, they’re not creating a new system or revising an existing one. |
| [11:45]Teacher | So here are some arguments put forth. What about this group? |
| Student | So we related this a bit to the fact that they’re just studying, trying to figure out how it works, not really contributing to it. |
| Student | But the reason we scored it so high as a four was because they’re taking measurements to test the parameters and capabilities of a machine. |
| Student | We just didn’t feel like it could be a five because of the point about it being studying. |
| Teacher[12:40] | To me, it sounds like we have one voice here that is most against the high rating. So hearing some of these arguments, what’s your thinking? |
| Student | So everybody is pointing out that they’re observing the mechanics of it but not necessarily changing it any way, just trying to figure it out. |
| Teacher | So I guess the question we now have in front of us is, well, they’re studying it. They’re not revising or creating the system. So the question before is: If all you are doing is just studying and trying to learn about a machine, is the fact that it’s a machine enough to call this engineering? |
| Student | No, you can do anything with a machine, [but] it doesn’t make you an engineer. You’re doing engineering practices. But you need to be applying specific practices like trying to improve it or make it more efficient or studying it with a purpose of doing those things. |
| Teacher | But according to this rationale, the suggestion is that, given that we’re taking measurements of a machine, it felt like engineering to us. |
| Student | I think the first point is important—collecting data to optimize use—because it seems like an important part of engineering to make the most efficient use of the equipment you have. |
| Student | That’s like what civil engineers do is make things more efficient. |
| Student | Or industrial systems engineers. |
| Student | Right |
| Student | A lot of my thinking is that I rated this low as a science lesson because they never explicit[ly] teach science content. It’s implicitly taught but not addressed like the projectile motion equations and stuff like that. They’re just optimizing a machine for use. |
| Student | This is the application of kinematic equations. |
| [15:15]Student | The application of science isn’t science; that’s engineering. |
| Student | All applications of science are engineering? |
| Teacher | Well, so we’ve raised questions. This is what’s important! The purpose of this activity is not necessarily to answer all the questions but to raise some questions. Here’s one of the questions we currently have. Have an idea that engineering is an application of science; it’s oftentimes referred to as that. But are all applications of science engineering? Is engineering simply the application of science, or is it the application of science **and** some other things? These are some of the questions we are wrestling with.And then we come back to this thing that I pointed out before. We have a machine within this scenario. What would they have to be doing in relation to this ball launcher to actually make it an engineering situation as opposed to something else? What would the something else actually be? Okay, so we’ve raised some questions then. Valuable and important questions, I think. |
| [16:30]Teacher | Let’s look at Miss West’s tenth grade Bio. Science? [All groups indicate a five.] So we have consensus that this is pretty science-y. What about engineering? [Threes and twos.] Okay, so lower than before, with some differences. I want to hear some rationales for why this felt like less of an engineering lesson than the first one. |
| Student | At first, I had it down as a five because I thought of it as students examining a system and they’re determining how different variables impact the system. But my group members told me . . . not told me, we had discourse, and they convinced me that they’re just investigating the system. They’re not doing anything with it. Can you guys speak a little bit more on that? |
| Student | Right, so, I was thinking that the simulation isn’t the point of the lesson. They’re not designing it or asking any questions about the simulated system being given. They’re wanting to draw conclusions about the dynamics of an ecosystem, and I feel like it’s too far separated. Like, the point of the lesson seems separated from the engineering concepts. |
| [18:10]Teacher | What other thoughts do people want to share about their ratings? One thing I might ask is: why not ones? |
| Student | Because there’s still a system involved, they’re still studying a system. That’s what I thought. |
| Student | Because engineers have to study systems to then do things with them. So, that is an engineering practice, but it’s not all the engineering practice. It feels like half of a practice. Which might just be science, I don’t know. |
| [18:40]Student | Well, I think so; my rationale’s a little different. I think the reason engineering isn’t a one is because they’re collecting data, which I would argue is an engineering practice, but other than that, they’re performing a study, which I think, well, my thinking is exclusive to science but . . . now I’m questioning that. |
| Teacher | Okay, so I’m hearing several arguments that are revolving around this point, but I want us to be careful about [that]. We’re noticing things like: Oh, we’re collecting data, and collecting data is a practice used by engineers. But collecting data is a practice used by a lot of people in a lot of different circumstances! Historians collect data. If a historian is going and collecting data from an archive, would we look at that and say, well, that’s an engineering practice; he must be an engineer? No, that doesn’t make sense.So we have to be a bit wary of some of this stuff. Some of these practices are very broad and utilized by a lot of different things, so we want to be careful if we’re going to make our judgments based on the presence or absence of one of these practices. That said, I think there’s some arguments up here that I think are worthwhile. I’m still curious to know: Why not ones? In what sense is this engineering beyond collecting data? Because I’m not convinced by that alone! |
| [20:30]Student | I want to say they make claims based on their evidence, but historians also do that. |
| Teacher | Sure do. |
| Student | And that’s a science practice as well. |
| Student | Those say “science and engineering practices” [gesturing at a list of practices on the wall]. So both scientists and engineers do all those things, right? |
| Student | Is making claims, though, for both? |
| Teacher | You’ve raised a question here that I think is important. He’s wondering, “do engineers make claims?” And I guess one of the questions we might ask here is—they have them listed as the science and engineering practices, and I may have foiled you by having these on the wall because I think this is somewhat misleading. Really, what we ought to be asking is: even if they are making claims, how do engineers make claims differently from how scientists make claims, which is different from how historians make claims, which is different from how philosophers make claims? Many fields do many of those things, and the devil is in the details. That’s what we’re trying to get at.So I do kind of regret having that poster on my board right now because those are too generic and too vague. I can’t really use them to make distinctions between different fields. And I’m pretty sure Miss West was not teaching philosophy despite the fact that students were making claims based on evidence, which is something philosophers do. I imagine most of you would probably agree. |
| [22:00]Teacher | So let’s move off of this one. An open question might be: to what extent is there is any engineering going on with Miss West, and why? But what about Mr. Green? |
| [22:20-26:50 omitted for brevity.] |
| [26:55]Teacher | Okay, we’ve raised some important points here, and I’m starting to get a sense of at least some commitments we’re willing to make, at least tentatively. I’m mostly interested in the engineering aspect because this is sort of the new piece to us that we’re trying to fold into our understanding of instruction. We’ve all identified so far that we’re looking at engineering as examples of applying scientific ideas. There’s some agreement that some of the hallmarks of making something engineering would be like revising, improving, optimizing, promoting efficiency. But there’s questions here as well. We’ve raised some of them where there’s some ambiguities. Because we can probably imagine situations where students may not be doing quite like what they’re doing in Mr. Green’s class, where they are very overtly designing and revising a system. We have some in-between moments with Mrs. Blake’s and Miss West’s class.So here’s what we need to do. I know, for some of you, you have some experiences taking courses in engineering. But I’m just sort of curious. How many of you feel like you’ve got an extensive picture of what engineers actually do out there in the world as professional engineers? How many of you feel like you have a very good picture of that? |
| [28:50]Student | I will say this, I took one engineering class—it was a freshman engineering experience—and I did not get much out of it. |
| Teacher | So, you claim no expertise based on that experience! |
| Student | But, my dad is an engineer. |
| Student | My fiancé is a PhD candidate in electrical engineering, and he complains about it to me a lot! |
| Teacher | Alright, so we’ve got some personal connections. |
| Student | I took an engineering course in high school at a vocational school. I also got to interact with higher level students who were doing aerospace engineering. |
| Teacher | So you’ve got a little bit of examples. Of course, we always keep in mind that if you have a family member as an engineer, you have one person’s perspective and experience. Engineering is a pretty broad field!So what I’m going to help us do, and especially for those of you who have less familiarity with this, who maybe aren’t so lucky to have a family member who is or becoming an engineer. Some examples could be very useful for us! Some examples from the real world, so that’s what I’m actually going to have us get into now.So here’s part two . . . .  |
| [30:00] | [Shifts to instructions for the stories.] |

**Appendix D: Transcript of Whole-Class Discussion During Part 2**

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| **Context:** In an elementary science methods course, the students have just finished working in their groups to record their answers to the “Making Sense of Stories” document. The teacher has been helping groups sort through the more puzzling questions on that document by offering clarifying ideas and pointing out key aspects of the stories. Groups have been talking through those questions for about 25 minutes, and the teacher has already addressed several important nature of engineering ideas with individual groups.  |
| [1:17:00]Teacher | I want to first take stock of why we went this direction and what we need to glean from this. I don’t want to stray too far from our main teaching purposes here, which is to say: we’re trying to get some information here that’s going to be relevant for making judgments for classroom instruction. We needed to get these perspectives from the real world to compare what’s going on in the classroom to what real engineering is all about. As you all read, oh boy, engineering can look really different across a lot of different fields. So what you were all wrestling with and figure out is what are the commonalities and what are the common threads. And of course, we do the same sort of things when we try to puzzle out what is doing science about, given that what an astronomer does versus what a chemist does is pretty different. Some people run experiments, some people never run experiments, and yet we call them all scientists.Same thing for engineering. It doesn’t always look the same, and one of the insights I hope you gained here . . . one of the questions I posed to you is: “What are the products that engineers are making?” And one of the important insights that came up for a lot of you is that not all of these engineers are actually making anything tangible at all. In fact, several of these engineers definitely aren’t. What’s an example of something an engineer might create—it’s a product of the engineer’s work—but it’s not a tangible thing? |
| [1:19:00]Student | So I read Kiana’s, and she was talking about the process, and so in that case, the product was the process, not anything tangible.  |
| Teacher | These sorts of production processes, by the way, are incredibly important in the real world of industry. It wasn’t included in my set of stories, but one of the engineers I interviewed worked for General Mills, and there’s a product that’s eventually created there—it’s a box of cereal. But what was she working on? She was a process engineer in the General Mills facility. What she was designing was the actual production process that takes the raw materials and somehow outputs a box of cereal which is . . . incredible. It’s like magic. But it’s not magic—someone had to design that process. So they’re not actually making the thing here, which is interesting.Even in cases where there is a tangible product that is involved, I think it’s worth noting . . . even if there is a physical product somewhere, someplace, if we think about what kinds of products engineers create during their work, clearly they’re involved in the creation of something tangible. Think about other examples where they’re not just working on a process. What are examples of the things that engineers are actually making? What are they handing off to somebody else? |
| [1:21:00]Student | We said they are either making a solution or a plan for a solution to hand off to a consumer that needs it. |
| Teacher | When we think of a plan, what sort of things do you all have in your heads? |
| Student | Maybe like a blueprint. |
| Teacher | That’s kind of what I picture, like a blueprint-y sort of thing. If you patent an idea, a lot of engineers will end up working for an organization that wants to patent what they designed. When you submit a patent, you submit these very detailed schematics to show that this is the thing. You’re not going to send off to the patent office the thing itself. You’re sending the blueprints, the sketches, the designs.So okay, how does this help us think about the instructional situation? Well, if you’re gonna be in a classroom scenario and you’re going to do engineering with kids, you want what you do to be reflective of the real world of engineering. This is the sort of products that engineers create. They’re not the ones physically assembling the stuff. What are they doing? They’re making the plans for these things, and sometimes it’s a process; it’s not even a physical thing itself. That’s important because when we look at what’s going on in the classroom, we might say, “Hey, look, there’s these kids, and they’re making a tower out [of] spaghetti.” I’ve seen that many, many times. Is that engineering? Well, not really. They’re building something. Lots of people build stuff. Carpenters build stuff. Construction workers build stuff. What does it mean to engineer something? Even if what they’re designing or developing is a structure, they are the ones planning that thing. That’s their product. Not the thing itself. A critical distinction. |
| [1:23:20]Teacher | As you were working through these different questions here, I asked several groups to share with me things they were wrestling with. Which of these questions do you want some more clarity on? |
| Student | Supporting ideas |
| Teacher | So, what kinds of things do engineers do to justify their products? I’m actually going to flip over here to the science side because I think that will be more familiar. So if you’re a scientist, and you’ve conducted a study, and you feel like you’ve generated some new knowledge about how the natural world works, you gotta defend your ideas to other scientists because you gotta convince people. Science is a communal endeavor. If you’re a scientist trying to convince other people, how are you gonna do that? What sort of things are you gonna use to justify your ideas? |
| [1:24:30]Student | You’re gonna use the data you collected. |
| Student | Build representations or show representations |
| Teacher | The data’s not going to speak for itself, for instance. What other things might you do to build your case? [no responses]I’m looking to my science and engineering practices right now . . . I see engaging in argument from evidence on here. What does it mean to engage in argument from evidence? |
| Student | Defend your claim |
| Teacher | [*Teacher’s Note: This was not a particularly successful part of the discussion. I should have had students refer back to the stories here to get some specific examples of what the engineers were doing to ensure that their ideas made sense. I didn’t think of that at the time and instead provided a more “general” description that was less clear.*]Perhaps using some logic, based on your data. So I’m coming over here to point out how you defend your ideas means doing this sort of stuff [the science and engineering practices]. You’re going to go out and collect data, and you’re going to use that to convince other people, not just yourself. Now engineers are collecting some data as well. They’re also trying to convince people, often somewhat different people. The things that they’re gonna draw upon are a little bit different. One of the things that engineers will do is make a prototype. They’ll set this thing up in the lab and test the heck out of it to see if it works. So when they turn it over and they have these designs, they can say, “Hey, we’ve tested this, and we know it’s not going to fail unexpectedly.” Think about how important that is and how important it is to justify your products if you’re a civil engineer who’s designing a building. And you’re gonna convince some company that not only is it going to be under budget and all this other, but it’s going to actually stand up. The consequences of failure are kind of high. Obviously, you are going to run some tests. You aren’t going to build a whole building first and then see what happens.But there’s going to be other sorts of things that you can use to convince somebody that your idea makes some sense. I believe one of the engineers, one part of one of the stories, said that if you can’t actually convince other people to use your product, you might as well not have made it. This idea of convincing other people is really important, but we’re using similar science and engineering practices—obtaining information, using argument from evidence—in many ways, it looks pretty similar across these two things, but the sort of arguments they might make in engineering land is a little bit different. It’s not just that my ideas make sense given the evidence but more like: we made the test, and we think it will work. Also sensitive to budget because money is kind of important in engineering land. Less so in science, although there’s funding issues too, but your ideas in engineering can’t cost way more than we can budget. So they’re going to make different sorts of arguments, convincing different sorts of people. |
| [1:28:00]Teacher | What are some other areas we want more clarity around? [No responses.]I’ll scroll down here to the bottom—goals and purposes. When I was interacting with some groups, a lot of people said that when they were distinguishing the goals and purposes of engineering versus science, they were coming down on similar lines to where we started today. But I’m hoping that you now have more specificity and concrete details for these things. One example that I thought was quite interesting that our group in the back was wrestling with: they were looking at the example of Suzanne, our agricultural engineer. For those who didn’t read that story, she develops monitoring systems for hog farming operations to keep track of the animal behavior and make sure they don’t do things that are going to harm themselves or others. Clearly, if you’re a hog farmer, you don’t want them injuring themselves or other hogs. And this group was wrestling with . . . okay, we see the goal and purpose there; we’re trying to deal with animal behavior and make that work better. How is that different from just being a dog trainer?It’s sort of a similar goal and purpose, trying to shape animal behavior. How do we separate it out from something that is neither science nor engineering, like training dogs? |
| [1:30:00]Student | Maybe like understanding why. If you’re just a dog trainer, if you get the result, you’re happy with it. But maybe engineers want to understand why what I did will work.  |
| Teacher | In what other respects is the goal of a dog trainer different from the goal of an engineer? |
| Student | Training a dog is handling more of conditioning and then behavior engineers can explore, Why and how? Questions like that. |
| Teacher | So you’re noticing maybe a level of complexity of what might be going on in the engineering situation. What are some other ways that these things are gonna differ? |
| [1:31:00]Student | Engineers might also be thinking how this might apply to other animals. A dog trainer will just be thinking about “how do I get this dog to do what I want it to do.” Engineers might try to find a more universal formula. |
| Teacher | I’m trying to come up with different examples of this. So like, what would differentiate a carpenter making a table versus some engineer who’s working in the factory that’s gonna produce a whole bunch of tables. Certainly, the tables sitting in front of you in this room right now, an engineer didn’t make those tables. But they were involved in the production of these tables because some company cranks out gobs of these tables. When you’re making something at scale, it’s that complexity that makes you need to leverage the engineering mentality.When you think about the goals and purposes of engineers, it extends beyond the creation of one particular or the achievement of one specific result, oftentimes. Oftentimes we’re trying to scale these things up in some sense. Apply these things to other similar circumstances. It’s another important example that has instructional implications to us. I’ve seen too many activities in classrooms that are billed as engineering but look a whole lot more like dog training or carpentry. And that’s an issue that all have to wrestle with as you think about how you engage kids in something that more authentically represents what’s going on in this field. |
| [1:33:00]Student | I have a question. So for the carpentry example, are you saying that wouldn’t be an engineer because he’s following someone else’s plan? |
| Teacher | Not necessarily because the carpenter might not be following anyone else’s plan. They might be doing truly creative work, and many of them do. The difference is really, when you think about what a carpenter is doing, they’re starting from materials and go all the way to the end product, and they’re just going to make this thing. They’re the one physically carrying out the production process themselves. Where if you’re an engineer, you’re just going to do the designing work, and you’re going to hand this stuff off to somebody else to implement, and usually it’s being done in a much more highly complex and large-scale operation. And that’s what ends up being a real difference. |
| [1:34:00]Student | So if you were in the classroom, you would only have students like make a plan or a design and not necessarily make a model or carry it out? |
| Teacher | Well, let’s think about this because this is a great question. There are times when we want, within engineering, we want to physically make something. But the reason we want to physically make the thing is so we can put it to the test. And you can figure out, collect that data to justify to somebody else that this thing actually works. That’s why we’re making the prototype, the model, to test it out. So it’s not really the end itself; it’s a means to an end. You’re just creating it so you can see what happens. That point is missed by many students. Many students focus on engineering as build time, making stuff. For obvious reasons—it’s fun! That’s the fun part, right? And of course, there’s gonna be some of that, but what we want to make clear to kids is that we’re gonna make stuff, but it’s for a reason, and the thing, the end point, is this plan, this blueprint, that comes at the end of the process. Just like in the science classroom, the end point is the knowledge of how this works. It’s not the data that’s the end point—that’s just a stepping-stone to the final thing. |
| [1:36:00] | [Transitions to revising the ratings of the scenarios.] |

**Appendix E: Additional Transcript of Whole-Class Discussion During Part 2**

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| **Context:** This is an excerpt of a discussion that occurred in the secondary science methods course from Appendix C. It is an excerpt of the longer conversation, partway through debriefing the “Making Sense of Stories” document. It illustrates some directions this conversation can go that are very different from what occurred in the transcript included in Appendix D.  |
| [1:14:00]Teacher | Next thing I want to touch on, and you all mentioned this thing. One piece of language that you came up with when you were addressing this idea that engineers solve problems. One thing that you pointed out is that scientists solve problems, too, but different sorts of problems. And that’s an important idea, and one thing you landed on is that engineers solve specific problems. I want to think about that a little bit. When an engineer is engaged in solving a problem, in what sense is it a very specific problem? What do we mean by that? |
| Student | It’s something that we know we theoretically can do. We have the knowledge to do it. But it’s so specific that no one’s created this exact system before. So somebody needs to do that. |
| [1:15:15]Teacher | So let’s take a specific example of that. You all have a bunch of computers in front of you. In general, we know how to make a computer. The computer as a broad-scale grand technology is sort of, as you said, we already know how to do this. We’ve been doing it for a while. But what about that specific computer that does these specific things? Why aren’t all computers exactly the same, if we know how to make them? |
| Student | Different applications. |
| Student | Different functions. Depends on the brand, depends on . . . |
| Student |  . . .the intended consumer? |
| Student |  . . .yeah, I was thinking about how like HP or Microsoft has one that’s five or six hundred dollars, but they’ll also make one that’s like a thousand dollars. |
| [1:16:20]Teacher | Yeah, so they’re making different versions, and this kind of raises the point of why you’d want to do this. Well, not every computer is built to solve the exact same problem. They are specific in some respects. Any engineering problem has a lot of specific context in mind if we consider the particular consumer in mind, the specific context it’s going to be used in. There’s a reason why sometimes we need a computer that has enormous computing capacity so we can run the atmospheric models to run the climate change models. We need an enormous computer. But other times, it’s not the problem we’re trying to solve. That would be very expensive.Same deal for . . . I’ll pick on the petroleum story . . . when a refinery calls you up and says, “we’re having these problems with our refining process,” they’re not asking the engineer to solve some theoretical notion of what the process of refining oil should be. No, they want the process that’s going on in this particular refinery. The details of that refinery are kind of important. That’s kind of different from how a lot of scientific problem-solving and puzzle-solving is gonna be. Think about scientific knowledge. Think about the laws we like to teach kids in our science classrooms. In what respects are those ideas absolutely **not** context-specific? |
| [1:18:20]Student | If you think about the late 1800s, early 1900s, everybody was focused on trying to find the fundamental laws of everything that could be applied to everything. Like germ theory, that’s one thing that Pasteur wanted to apply to everything because it was extremely useful and could be applied to all these different things. You could get specific with it, but the basis of it was this. |
| Teacher | So that basis is what scientists tend to like a whole lot. That’s really the golden nugget, the fundamental ideas. When you think about the law of universal gravitation, what makes that such an awesome idea? Well, because it’s universal! Doesn’t matter where you are in the whole universe. Well, we’ve updated it with Einstein’s ideas, but it’s not because his ideas are more specific—far from it. They’re even more universal and generalizable. They work under an even broader range. That’s very different in terms of how science and engineering are focusing on the world. Scientists like to generalize and get context, nonspecific knowledge that you can apply anyplace, and it always works. For an engineer, that’s nice and could be useful, but their problems are highly specific.Think about the implications of that if you’re gonna be incorporating some engineering into the classroom. I want to have my students doing an engineering problem. I better have some very specific contexts in mind; otherwise, this problem doesn’t make sense as an engineering problem.  |
| [1:20:00] | [Teacher shifts to discussing a different point from the “Making Sense of Stories” document] |

**Appendix F: Transcript of Whole-Class Discussion During Part 3**

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| **Context:** This is a continuation of the discussion that occurred in the elementary science methods course in Appendix D. After that conversation, students had about 10 minutes to revise their ideas about the scenarios in small groups. They have come together to discuss changes that they want to make to their ratings and rationales. |
| [1:43:30]Teacher | I’d like to start with situation number three. We had some disagreements here about what its rating ought to be. What do we want to change? |
| Student | We left our rating the same, but we thought there should be some problem posed. |
| Teacher | And not just any problem, right? We’d have to have some sort of engineering problem that’s posed. And let’s spitball an idea here, based on this stream table thing. What might be an engineering problem you could pose? |
| Student | Like, how do we make the stream minimize erosion or something like that? |
| Teacher | And maybe we could dress this up in some context where you’d want to do such a thing. In this case, we’re introducing a problem that needs to be addressed. Were you originally one of our threes? |
| Student | We were a two. |
| Teacher | Okay, what about our threes? Stay there? Downgrade? Upgrade? |
| Student | Downgrade to a two. |
| Teacher | Why a two? |
| [1:45:00]Student | We said because they’re not really designing anything. Whatever explanation they’re coming up with, it’s not something that they have to defend. |
| Teacher | And even if they’re coming up with explanations for the stream table, that would be science, right? There’s plenty of fine science going on here in terms of generating explanations of how erosion happens in the world. But there’s something missing in terms of engineering. What about our other group that had given it a three? |
| Student | We gave it a one. |
| Teacher | All the way down to one. Similar reasoning? |
| Student | We just didn’t see any evidence of them making a design. They were just studying the data. |
| Teacher | Very consistent with science. And there’s potential here if you want to take things in the engineering direction. And this is not to say that what’s happening in Mr. Green’s classroom is problematic. It could be [a] fine science lesson. But it seems that we’re convinced it isn’t engineering. |
| [1:46:20]Teacher | Let’s go over here to scenario two. You were all convinced that this was pretty clearly engineering. Did any of you change your ratings? |
| Student | The same. |
| Teacher | Do we feel we have a more clear rationale than before? If so, is there any additional reasoning that we could add to our list of reasons? |
| Student | It specifically says that they made a plan in there. |
| Teacher | So this is getting at this idea that we’re doing some designing. Any other things you noticed that reinforce our choice?  |
| [1:47:20]Teacher | Okay, let’s hop over to Miss Blake then. Lots of disagreement initially. Who wants to upgrade or downgrade? |
| Student | We were at two, and now we’re at one. |
| Teacher | Any other reductions? |
| Student | We actually had science reduced to a one, and then engineering went to a five. |
| Student | What?? |
| Student | I’m not convinced. |
| Teacher | Let’s sort this out. What are we thinking? |
| Student | We thought that they had to make a plan on how to make the biggest bubble. The problem was that the bubbles were too small, and we wanted bigger bubbles, and they tested it out by having different combinations and justifications. |
| Student | Was the problem that the bubbles were too small, or were they just trying to figure out how to make big bubbles? |
| [1:48:30]Teacher | Sounds like what we’re wrestling with is the question we had before. What exactly is the problem, and is this a legitimate engineering problem? I want to hear from a couple of our other groups. |
| Student | I think the science question is which soap mixtures they want to test and which makes the biggest bubbles, which I think is a science question because they’re getting at the composition of the bubble and the ratio of soap to water. But you could easily make that an engineering question by making the guiding question: “How can we make the biggest bubble using soap and water?” |
| Student | So we’re staying at 4.5 for engineering. |
| [1:49:30]Teacher | What about this group? |
| Student | We still think it’s a five for science and three for engineering. |
| Teacher | What do you think about the nature of this problem? Does it seem like the question is an engineering question or a science question? |
| Student | I agree with [student] that it’s a science question, but I think that there’s something there that could be an engineering question instead. |
| Teacher | Ultimately, I think it’s not terribly important how we come down on these ratings. Where we do have consensus is on this issue of: it depends on how you frame this activity to the kids, and the way that you pose the problem itself is going to dictate how this activity goes down in your classroom. Whether it’s more an investigation of let’s figure out how these different combinations of materials affect the size of these bubbles—I just want to learn about this and figure out how this works—versus, today, you’re gonna design a formula for a bubble solution, and we’re gonna try to make the best bubble solution we possibly can—you’re gonna need to figure out which is best. Think about how those are very different questions, and it can actually sculpt the lesson quite a bit, making it go one way or the other way depending on what stance you want to take. |
| [1:51:10]Teacher | So here are a couple of points I want to wrap up with. If there’s a major theme we’re coming back to, it’s a question you posed here: What is a good example of engineering teaching? What are we trying to accomplish here? What’s the point?Our rationale for doing engineering with kids is that it’s an opportunity for students to apply their scientific ideas to some sort of problem-solving situation. Seems like a very logical thing to do from time to time. What we’re wrestling with here is how to make something authentically an engineering experience. And that’s what good engineering instruction looks like. Just like when designing some scientific investigation, you want it to be authentic to some extent.We want to be careful with the labels we use in the classroom. Just like going outside and playing around in the playground is a lot of fun, it’s not science. Turning it into an investigation, you have to position yourself as a scientist. And the same is true for the engineering piece.So as you think about this, how do you make it good? I really say two things. Number one, it’s got to actually be relevant and connected to those science ideas you’re teaching. Number two, how do we make it authentic and make it represent what engineering is all about. My hope is that you’ve gained some clarity around that. And at the very least, as you start from these scenarios—and they were brief scenarios of classroom instruction—what I think is the most valuable thing to think about is: what would it take to make this activity a more authentic one. That’s the essential question. |
| [1:54:00] | [Transition to wrap-up.] |