# Chapter 11
# From Lab to Lecture? Science Teachers' Experiences Translating Materiality in Lab-Based Research Experiences into Classroom Practice

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## 11.1 Introduction

The activities in which scientists and engineers engage have received substantial attention in recent documents shaping science education in today's K-12 classrooms in the United States, perhaps most visibly with the Next Generation Science Standards (NGSS Lead States, 2013). Indeed, in outlining the three key dimensions used to form each of the NGSS standards (i.e., practices, crosscutting concepts, and disciplinary core ideas), the role of the practices of science and engineering is described as follows:

> The practices describe behaviors that scientists engage in as they investigate and build models and theories about the natural world and the key set of engineering practices that engineers use as they design and build models and systems. The [National Research Council] uses the term practices instead of a term like "skills" to emphasize that engaging in scientific investigation [and/or engineering design] requires not only skill but also knowledge that is specific to each practice (Three Dimensional Learning section, para. 2).

Given this emphasis, we must consider how the K-12 teachers responsible for developing learning experiences centered on the practices of science and engineering might themselves develop meaningful understandings of these practices, including the vital role of the apparatuses with which scientists and engineers engage while doing their work. This study describes one medium for supporting teachers' understandings of the role of apparatuses and materiality in science and engineering, as well as for considering how such understandings might relate to classroom practice in K-12 settings.

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## 11.2 Materiality in Science and Engineering

In their seminal work *Laboratory Life: The Construction of Scientific Facts*, Bruno Latour and Steve Woolgar (1979) began their exploration of the work of scientists with an excerpt from observer field notes that transcribed the verbal exchanges and actions of several workers in a laboratory over a 5-min period of time. This excerpt was followed by a brief "observer's story" that summarized the course of a typical day in the same lab (pp. 15–17). Likewise, Latour (1987) introduced his subsequent examination of the activities of scientists, *Science in Action: How to Follow Scientists and Engineers Through Society*, by providing brief vignettes that described the work of researchers in three different, yet related, lab settings. Through such introductory accounts, these authors provided readers initial glimpses into the world of laboratory work often unseen by outsiders, which were then expanded upon throughout the remainder of the two texts. Latour explained his intent to study "science and technology…through the back door of *science in the making*, not through the more grandiose entrance of ready made science" (p. 4, emphasis added) in order to more fully understand scientific activity.

One particular aspect of science and engineering activity problematized by Latour (1987), among others, is the role of instrumentation in the production of scientific knowledge. Ronald Giere (2002), for instance, drew upon Edwin Hutchins' (1996) description of distributed cognition, which posited that knowledge is not maintained solely within the mind of an individual; instead, it extends among and beyond humans, including the physical tools that are used when carrying out a task. Therefore, Giere observed researchers' interactions both with one another and with instruments used to conduct their investigations and concluded that "to understand the workings of the big cognitive system [of scientific research] one has to consider the human-machine interactions as well as the human-human interactions" (p. 292). Karen Barad's (1998) work further addressed this precise issue through her framework for agential realism, prioritizing "an understanding of the role of the human and nonhuman factors in the production of knowledge" (p. 89). More recently, her focus on agential intra-action (Barad, 2003) has provided additional focus for considering the role of material instruments in the everyday activity of scientists and engineers. According to Barad (2003):

> Apparatuses are constituted through particular practices that are perpetually open to rearrangements, rearticulations, and other reworkings. This is part of the creativity and difficulty of doing science: getting the instrumentation to work in a particular way for a particular purpose (which is always open to the possibility of being changed during the experiment as different insights are gained). Furthermore, any particular apparatus is always in the process of intra-acting with other apparatuses… Phenomena are produced through agential intra-actions of multiple apparatuses of bodily production… That is, it is through specific intra-actions that phenomena come to matter—in both senses of the word. (pp. 816–817).

Therefore, an understanding of the agential intra-actions among scientists, engineers, and apparatuses is fundamental for fully comprehending the notion of *science in the making*.

One potential approach for building understandings of science in the making and agential intra-action is to provide pre- and in-service teachers with opportunities to actually participate in authentic science and engineering practices. Given that teachers may not necessarily be provided with the chance to engage in such practices during their own educational experiences and training, numerous programs exist that are designed to address this need. One of the most pervasive programs in the United States aimed at engaging teachers in science and engineering research is the National Science Foundation-funded (NSF) Research Experiences for Teachers (RET) professional development programs, which are housed at universities nationwide in a variety of fields within science, engineering, and computer science. The case addressed in this chapter describes the research experiences of three high school science and engineering teachers who participated in a summer RET in Engineering program, specifically focusing on the teachers' agential intra-actions with apparatuses through their work, as well as the ways in which they carried these intra-actions back into their classroom teaching.

## 11.3 Methods

### *11.3.1 Study Context and Participants*

Participants in this study applied and were selected to take part in a 6-week summer RET in Engineering Professional Development Program designed for middle and high school science, technology, mathematics, and engineering (STEM) teachers. Teachers were matched with university faculty based on alignment of their classes taught and the faculty member's research, as well as the teachers' overall interest in this research. Teachers then collaborated with researchers to work on small-scale projects related to the professor's ongoing work. According to the NSF (2007):

> [The] Research Experiences for Teachers (RET) in Engineering program supports the active involvement of K-12 teachers and community college faculty in engineering research in order to bring knowledge of engineering and technological innovation into their classrooms. The goal is to help build…collaborative partnerships between K-12 science, technology, engineering, and mathematics (STEM) teachers, community college faculty, and the NSF university research community by involving the teachers in engineering research and helping them translate their research experiences and new knowledge of engineering into classroom activities. (Synopsis, para 1).

In order to maximize the teachers' involvement in research, participants spent most of the 6-week program working in labs on their projects, with 3-day introductory and concluding periods bookending the research experience. During the final days of the program, RET participants were asked to create a curricular unit based on their research experiences, which was to be enacted during the following academic year in a science or engineering class.

Among those teachers who were selected for participation in the iteration of the RET program addressed here, a total of six were first-time program participants with minimal previous experience in science and engineering research. These first-time program participants were identified for study in an attempt to isolate the impact of this type of professional development program. Of these six teachers, three teachers from three different schools were selected for focus in the case study presented here. Ryan, who had been teaching for 32 years prior to participation in the RET program, taught physics and engineering in a private K-12 school. Joshua taught physics in a public, suburban high school and had been teaching for 8 years prior to participation in the RET program. Finally, Sarah, who taught life science, biology, and anatomy and physiology, had only been teaching for 1 year prior to her participation in the RET program. She taught in a public high school in a different suburban school district from the one in which Joshua taught. Therefore, a range of teaching backgrounds, school contexts, and content areas taught were represented across these three study participants. Additional information about the criteria for their selection, as well as detailed information about the lab settings in which study participants conducted their RET work, can be found in the case description that follows.

### *11.3.2 Data Collection and Analysis*

Data for this case study include documentation of participants' research experiences during the 6-week professional development program, as well as the teaching of their RET-based curricular unit during the subsequent school year. During the RET program, study participants were asked to keep detailed records of their daily research activities, including the purpose of their role in and the roles of any other individuals with whom they interacted in each activity. Although these logs were generated on a daily basis, completed logs were submitted at the end of each day or week, depending on the preference of the study participant. In addition to their daily activity logs, study participants wrote brief reflections at the conclusion of each week considering what they learned and its potential impact on their classroom instruction.

In order to verify and discuss in greater detail what was recorded in participants' activity logs and weekly reflections, I conducted individual, semi-structured interviews with each of the study participants during the first, third, and fifth weeks of their research placement. These interviews were conducted in or near the lab space in which each participant worked during their research placement and were scheduled at the teachers' convenience. Each teacher's activity logs and weekly reflections were available during his or her interview in the event that further explanation or clarification about their contents was needed, such as verification of the roles of the individuals with whom they interacted during their research and/or more detailed descriptions of what the teachers were physically doing during their research placement. Each interview lasted approximately 15–30 min and was recorded and transcribed for analysis.

During alternating weeks (i.e., weeks 2 and 4 of the research placement), I observed study participants directly while they worked in their labs at a time of their choosing, which was indicative of their typical research activities in order to obtain a better understanding of the settings in which they worked and their day-to-day activity. Each visit lasted approximately 1 hour, and I recorded field notes during all visits. These interviews and lab visits were designed to triangulate data provided through study participants' daily activity logs and reflections.

Following the conclusion of the 6-week RET in Engineering program and the study participants' return to teaching, I conducted observations of lessons taught as part of the curriculum unit designed by each teacher during the conclusion of the RET program. These curriculum units were intended to reflect a student-appropriate version of the content and nature of the scientific work in which each teacher had engaged while completing his/her research placement. Although agential intra-action was not an explicit focus of the RET program, nor a consideration for curriculum unit development, the lessons developed as part of these curriculum units were of interest because they provided the best opportunity to reflect each teacher's unique experiences with material resources in the lab in his/her own classroom instruction. Therefore, the selection of the three focal teachers discussed here was based on the fact that the curricular units that they developed were longer in duration than those of the other first-time RET participants. Hence, I was able to observe the focal teachers' RET-related instruction more frequently (i.e., five times each as compared with only three times for other first-time participants). This allowed me to obtain a more complete picture of each focal teacher's instructional approaches as exemplified by the RET-based curriculum unit, particularly the extent to which his/her research experiences with material resources were carried back to the classroom. Each observation lasted approximately 50 minutes, although some class periods were longer or shorter, depending on a particular school's schedule. During all lessons observed, I generated field notes to document the instructional strategies employed (e.g., lecture, inquiry-based activities, class discussions, textbook work), the social organization of these activities (e.g., individual work/small groups/whole class, directions provided, roles of students and teachers, materials provided), and the nature of the content communicated (e.g., discipline-specific information versus interdisciplinary content as expressed both verbally by the teacher and through course assignments). When possible, these lessons were also video-recorded so that I could review certain elements of each lesson as needed. Artifacts collected during observations were limited primarily to materials provided by the teachers (e.g., handouts, worksheets) and were intended to ensure a thorough record of the instruction that took place during each observed lesson. Teachers were asked to provide copies of any materials distributed and used by students during these lessons, particularly those used as a basis for discussion or group activities, so that I could more effectively follow the progression of each lesson and provide a richer qualitative description of each study participant's instruction.

A grounded theory approach (Strauss & Corbin, 1998) was used during analysis of all data to support the exploration of the cases presented here. According to Yin (2014), "the distinctive need for case study research arises out of the desire to understand complex social phenomena" (p. 4). Therefore, I define the "case" in this study to be the agential intra-actions experienced by teachers through a summer research program and their translation to the classroom.

## 11.4 Findings

In order to describe the case presented here, I will first draw comparisons among the study participants' experiences with science in the making through agential intra-action while conducting research in their lab placements. This is intended to highlight the breadth of opportunities provided for teachers through such programs. Following this, I will consider the ways in which study participants brought these experiences to bear on their own classroom instruction.

### *11.4.1 Material Intra–actions in the Lab*

*Contexts for Research* Although all teachers were placed in laboratories within the School of Engineering with which the RET program was affiliated, Ryan, Joshua, and Sarah worked in separate labs and on vastly different projects. Ryan worked in a lab focused on medical image processing for real-time use in surgical interventions for neurological disorders. He developed his own project, which centered on computer modeling of electric fields in the brain during stimulation by implanted electrodes, in consultation with his cooperating principal investigator (PI), and was able to develop and follow his own research methods while working toward his project goals. In his daily activity logs and bi-weekly activity interviews, Ryan indicated that he interacted frequently with a range of university research personnel, including research faculty other than his PI. Approximately halfway through his research placement, Ryan had the opportunity to observe a surgical procedure that drew upon the research of the lab.

The lab in which Joshua was placed explored the medical applications of mechatronics. Rather than contributing to the overall research goals of the lab, his project focused on the redesign and development of a haptic paddle device used in undergraduate and graduate courses at the university (Fig. 11.1 shows a haptic device.). Joshua was able to devise his own methods for the device redesign, but he was also able to consult frequently with graduate students in the lab when needed. While placed in the lab, Joshua attended weekly lab meetings, as well as a multi-lab meeting that brought together several labs for discussion of their ongoing work.

Sarah assisted in the preparation of bone samples for mechanical and imaging-based testing in order to help advance the lab's work on medical imaging for the evaluation of human bone strength. In completing her project, Sarah worked closely (often side by side) with a graduate student in the lab. She also had the opportunity to attend a conference about medical imaging hosted at the university, as well as a seminar related to her lab's work.

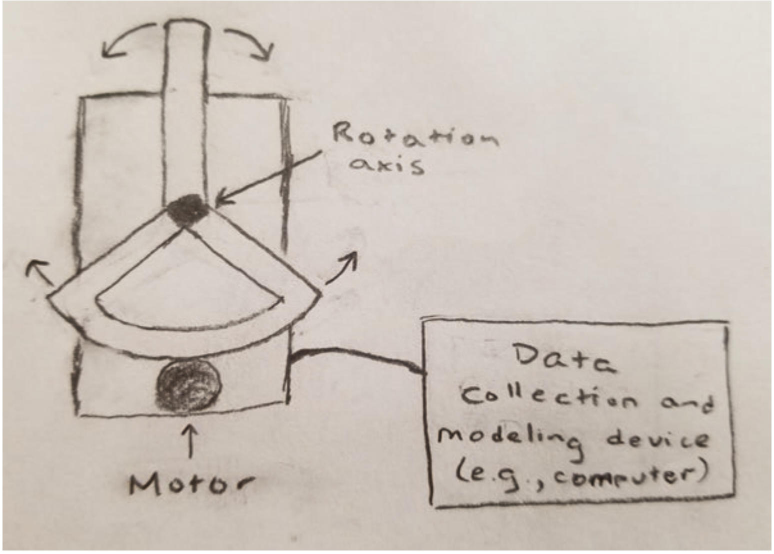


**Fig. 11.1** Haptic device

*Use of Apparatuses in Research* The different research projects on which each study participant worked did, of course, provide varied opportunities for interactions with a range of apparatuses. For Ryan and Joshua, their projects allowed frequent intra-actions with computers, as well as other apparatuses relevant to their particular research. The majority of Ryan's work took place on a computer, as he focused primarily on writing code to improve the effectiveness of the computer-based models. Ryan's observation of a lab-related surgical procedure provided him the opportunity to witness directly the potential impact of his work in a clinical setting. In an activity interview following his observation of the surgery, Ryan explained that this experience enabled him to comprehend the existing surgical procedures, including the ways in which the surgical team used the information from the lab's computer models to guide their implantation of electrodes within a patient's brain, and how the work he was doing would ultimately help expedite and improve the efficacy of the process (Ryan Activity Interview #2). Therefore, he not only engaged in agential intra-actions through his computer modeling activities, but he also observed the ways in which medical professionals engaged with the computer-based models to physically manipulate surgical instruments most effectively.

As noted previously, Joshua's project was not intended to further the overall research goals of the lab in which he worked. In spite of this, he had opportunities to engage in agential intra-action through his redesign of the haptic paddle device. In fact, the haptic paddle itself was intended to serve as an instrument to facilitate human/computer intra-action. As Joshua described, "the overall device, this haptic paddle, is to simulate…virtual space. So if you see something happen on a computer screen, the idea's that you feel it through this paddle" (Joshua Activity Interview #1).

Joshua initially spent a great deal of time interacting with and researching existing haptic paddle devices to help him develop plans for the redesign of the device. Ultimately, this led Joshua to generate computer-based models for the redesign, revise these plans, write computer code to control the haptic paddle, and source parts for the device with the aim to construct a prototype of the redesigned paddle. For this reason, of the three study participants, Joshua appeared to have the most multilayered, direct experiences with agential intra-action during his research placement.

Unlike Ryan's and Joshua's research experiences, Sarah's research did not involve computer-based work. Instead, her material intra-actions primarily involved the tools and instruments used to prepare bone samples for the evaluation of their physical strength via mechanical testing and medical imaging, as well as the bone samples themselves. In order to prepare the samples for testing and imaging, Sarah worked alongside a graduate student to clean the samples, often using a scalpel to remove soft tissue and/or the marrow from the bone, and then use a diamond saw to cut the bone into smaller pieces (Sarah Lab Visit #2). Although the ultimate intent of Sarah's project was to participate in mechanical testing and medical imaging data collection, that point was not reached during her time in the lab, as the apparatus for preparing the bone further for these processes had yet to be developed. Nevertheless, the very issue of instrumentation was problematized for Sarah by her inability to test the bone samples due to this lack of the required apparatus.

As is evident from these accounts, the opportunities for agential intra-action during these teachers' research placement varied widely. Ryan's experiences were confined primarily to the computer; therefore, the products of his work were relatively less tangible than those of the other study participants. However, it is worth noting that the intangible nature of his work did not preclude Ryan from intra-action with matter beyond the computer itself, as these intra-actions merely took virtual form. Using the computer to model the human body allowed Ryan to visualize and interact with structures that were otherwise inaccessible to him, thereby shaping his understanding of the modeled system and, ultimately, his coding of the model. These recursive intra-actions reflect how "participants and their technology become entangled and both the participants and the technology are changed as a result" (Milne, 2015, p. 320). Furthermore, Ryan had the unique chance to see how the modeling on which he was focused could be translated to more tangible apparatuses in clinical practice. Joshua's project did not provide him with much contact with the apparatuses used in the lab's ongoing research, but he worked with computers in several capacities (i.e., researching devices and sourcing materials, generating models for the redesign, and writing code to control the haptic paddle device), as well as with the haptic paddle device itself. This hybridized experience provided Joshua with the most direct connections between computer-based intra-actions and intra-actions with other apparatuses. Finally, although Sarah's project as intended may have provided a similarly hybridized experience, the lack of a required apparatus prevented this from occurring. Instead, her experiences were confined primarily to the instruments used to clean the bone and make the initial rough cuts to the samples in preparation for more fine-tuned cutting/shaping for mechanical and imaging-based testing.

### *11.4.2 Material Intra-actions in the Classroom*

*Lesson Overviews* As noted previously, all three study participants were observed during the teaching of five lessons, all of which were part of the curriculum units they developed during the RET program. Ryan, the only study participant who taught in a private school, developed a series of lessons that tied closely to the topic of his own research. This curriculum unit asked his students (grades 9–12) enrolled in his engineering class to work in groups to develop a museum exhibit explaining and demonstrating computer-guided surgery in the brain intended to alleviate the symptoms of Parkinson's disease. Throughout the unit, which spanned several weeks in length, students first worked in small groups to research different aspects of the disease, surgery, and related medical imaging, sharing their brainstorming products through online document-sharing services; students then shared their expertise with the other groups in the class through presentations utilizing PowerPoint, online videos and simulations, a student-constructed model of an electromagnet, and accompanying printed materials. The students subsequently met in new groups to develop models and other exhibit materials that would explain the surgery to museum patrons. One group, which was focused on describing the surgical procedure itself, was provided with a sample device (called a "platform," which was loaned to the class by researchers at the university) that could be placed on a patient's skull to help guide the placement of the electrodes/leads to be inserted into the brain. Another group worked on running computer programs to display MRI brain images and consulted with a computer programmer in doing so, while yet another refined the electromagnet model. Students consulted with one another through informal discussions and roundtables in order to solicit feedback as they prepared their final contributions for the museum exhibit.

In her anatomy and physiology class for students in grades 11 and 12, Sarah introduced a lesson that also related to her research experiences quite clearly. Her curriculum unit, focused on bone structure and formation, presented her students with a scenario in which she asked them to diagnose the condition (i.e., osteoporosis) of a hypothetical patient who had fallen and broken her hip. Sarah provided students with the results of a DEXA scan to assist them in their diagnosis and also asked them to determine possible causes for the condition. Finally, the students were asked to identify potential preventive measures that the patient and/or her descendants could take moving forward to minimize the risks of the condition. Ultimately, students were asked to work in groups to make a public service announcement about the condition presented in the scenario. In learning about the skeletal system, osteoporosis, and the risks of this condition, students worked in groups to take on the role of travel agents to create travel brochures for the human skeletal system, listened to lectures addressing bone formation and provided written responses to questions reviewing the lecture's content, and engaged in a station activity in which students reassembled a disarticulated skeleton, used x-ray images to locate a break in a bone, and used a microscope to look at slides of bone samples. During the concluding lesson of the unit, students worked in groups to generate their public service announcements by creating a poster or a video, using classroom computers to do so as needed.

Unlike Ryan and Sarah, whose RET-based curricular unit topics were reflective of their research, Joshua's lesson topic departed quite radically from his research focus. Rather than using his work with the haptic paddle as the basis for his lessons, he instead asked his 11th- and 12th-grade physics students to collaborate in groups to determine whether it might be possible to replace a ruptured Achilles tendon. In so doing, students used computers to research current treatment plans and their limitations and submit their findings to a shared online space; engaged in a lab activity exploring Hooke's law, spring constants, and elasticity by hanging weights from springs and measuring displacement; conducted computer-based research on materials to be used as a replacement for a ruptured Achilles tendon; and created a PowerPoint-based sales pitch designed to convince orthopedic surgeons to use the selected replacement material and that they could "defend…on physics principles" (Joshua Classroom Observation #4).

*Apparatus and Language Use During Instruction* Although all three study participants provided learning opportunities in which students interacted with material resources during their RET-based curriculum units, the extent to which these experiences mapped onto the teachers' research experiences varied widely. In spite of the fact that Ryan's agential intra-actions most directly involved computers while working in the lab, his unit addressing deep brain stimulation (DBS) surgery provided students with an array of material resources, including the surgical platform and leads used during DBS, and materials to construct an electromagnet. In these ways, Ryan appeared to draw heavily upon his experience observing a surgical procedure during his time in his research placement, as he tried to provide students with the most authentic experience with these materials as possible within the constraints of the classroom. Further mirroring Ryan's agential intra-actions in the lab, students were encouraged to use computers for multiple purposes, from conducting online research to manipulating medical images and computer-based models, much as Ryan himself did during his research placement.

Consideration of "the conjoined material-discursive nature of constraints, conditions, and practices" (Barad, 2003, p. 823) through analysis of the types of language employed in Ryan's classroom during these lessons provides additional insight into how his lab-based agential intra-actions carried into his instruction. While engaging in the instructional activities noted above, classroom discussions echoed the technical language that Ryan used in the lab setting. That is, both the teacher and students used clinical terminology related to brain anatomy (e.g., subthalamic nucleus, substantia nigra); the physiological basis of, impacts of, and treatments for Parkinson's (e.g., dopamine, tremors, and L-dopa, respectively); medical imaging techniques (e.g., the role of electromagnets in MRI); and the materials and procedures of DBS surgery (e.g., platform, leads). Although Ryan did not engage students in computer coding as he had done during his research placement, he provided students with code that he had written for them and that aided them as they selected and manipulated brain images (Ryan, Classroom Observation #4). This process, too, introduced students to language associated with such computer-based models (e.g., volume, slice) which, in other contexts, takes on very different meanings. The adoption of language by both Ryan and his students throughout this unit of instruction underscores this material-discursive nature of matter, as all classroom constituents used technical, context-specific language to construct their understandings of the material resources with which they intra-acted. Furthermore, although some relevant terminology was initially raised by Ryan as he introduced the unit of study (e.g., MRI, computer-guided surgery), most language use emerged and was refined as students conducted their independent and group research and, in some cases, constructed physical models of related apparatuses.

Sarah likewise provided students with a variety of learning activities related to her research placement. However, given that most of her lab activities focused on cleaning and cutting bone samples using a diamond saw, it is perhaps not surprising that the agential intra-actions with material resources that students experienced in these lessons did not closely reflect her own experiences. Sarah's students did have opportunities to manipulate bone models, much as Sarah manipulated bone samples, as well as to attempt to interpret x-ray images, which would have connected to the imaging work that had been planned for Sarah's project. She also included opportunities for students to interact with other apparatuses in her curricular unit, such as their use of microscopes to look at slides of preserved bone material. Again, while Sarah herself did not utilize these particular apparatuses during her research experience, she made a concerted effort to allow students to engage with apparatuses through experiences related to her research placement, even if tangentially.

Like Ryan, Sarah introduced technical terminology related to her research from the outset of her curriculum unit. The initial challenge posed to the students asking them to diagnose the fictional patient's condition included clinical language and acronyms such as DEXA scan and BMD (i.e., bone mineral density). Subsequent lessons in the unit introduced students to the scientific names for different bones of the human body (e.g., "patella" rather than "kneecap"), as well as bone structure and development (e.g., spongy and compact bone, epiphysis, osteocytes, ossification). Although activities earlier in the lesson sequence, such as the creation of a travel brochure for the human skeletal system, did not directly reflect the activities in which Sarah engaged during her research, they did encourage students to transition to the regular use of the language that Sarah encountered during her time in the lab. When introducing new vocabulary during a lesson presentation on bone development, Sarah pointed out certain terms that related to the students' challenge of diagnosing their "patient." She also integrated such language use during a bone lab activity (i.e., looking at slides of bone tissue, examining x-rays of bone fractures, and reassembling a disarticulated skeleton), as well as when students created their final public service announcements at the end of the unit of study. For instance, as students examined an x-ray of a fracture to the calcaneus during the bone lab, they used the x-ray image to visualize the damaged bone and simultaneously referred to the answer key provided to reinforce the notion that *calcaneus* is the scientific name for the heel bone. During this same lab session, students conversed to reassemble a disarticulated skeleton using the technical language associated with each skeletal structure. In addition to using terms such as *phalanges* to describe the bones of the fingers and toes, the students also utilized common clinical abbreviations such as

*C1* and *C2* to refer to different cervical vertebrae in the model skeleton (Sarah, Classroom Observation #4). In terms of language, the prevailing focus of this curriculum was on anatomical and physiological terminology rather than apparatuses used for measuring bone mineral density (i.e., the DEXA scan) or other forms of medical imaging (e.g., x-rays). Therefore, the material resources with which the students intra-acted were incorporated into the curriculum unit to support their developing understanding of lesson content, especially relevant vocabulary; meanwhile, this developing understanding simultaneously facilitated their intra-actions with such materials.

Unfortunately, despite his numerous experiences with agential intra-action during his time in the lab, Joshua could not find a way to relate his work to his courses effectively, and his departure in his unit topic reflects this disconnect. It is worth considering whether this was reflective of the fact that he did not work on a project aimed at advancing the research goals of the lab but instead focused on refining materials (i.e., the haptic paddle) used in undergraduate and graduate coursework. Perhaps, had Joshua had the opportunity to delve into the field of mechatronics research, he may have found a clearer connection to the classes that he taught. Conversely, one might argue that his work with the haptic paddle to be used in university classes provided a natural opportunity for Joshua to bring such an apparatus into his own classroom. However, given that this was not possible, Joshua created a curricular unit more directly related to his course content. This unit, focused on proposing a material to replace a ruptured Achilles tendon, largely centered on student intra-action with computers as they conducted their research but also allowed them to interact with materials such as weights, springs, and measurement instrumentation as they explored Hooke's law. Although not related to Joshua's research, students were afforded some opportunities to experience the agential intra-action that permeates science and engineering research.

Despite these affordances, the language used throughout Joshua's curriculum unit primarily focused on physics principles deployed to support students' reasoning for their suggested materials to replace the Achilles tendon. That is, students were expected to take certain principles, such as Hooke's law (specifically spring constants), into consideration when they explained the viability of their proposed material. Like Sarah's students, Joshua's students had the opportunity to draw upon language (e.g., fibrin, collagen fiber, graft) from related fields (i.e., anatomy and physiology) as it arose during their research into potential replacement materials, but most discussion centered on content directly related to broader physics course objectives. In fact, Joshua encouraged his students to focus their attention on such content when he reiterated that "All we're looking for is for you to be able to defend it on physics principles, not necessarily medical… We chose it because of this law, this principle" (Joshua, Classroom Observation #4). Therefore, it appeared that the types of agential intra-actions that Joshua experienced during his research experience were more difficult to reproduce in his own classroom, perhaps given the tenuous connection between his research experience and the focus of his curriculum unit.

## 11.5 Conclusion

As Barad (2003) stated, "We do not obtain knowledge by standing outside of the world; we know because 'we' are *of* the world" (p. 829). This statement underscores the importance of engaging teachers and students alike in the agential intra-actions that characterize science and engineering. Taken together, the research experiences of the three teachers described here reflect the varied opportunities for agential intra-action, to be of the world of science in the making, by participating in professional development programs aimed at providing authentic science and engineering research experiences. Furthermore, the ways in which such intra-actions were carried back to the classroom were inconsistent, at best, with respect to how classroom instruction reflected the role(s) and form(s) of such intra-actions.

With respect to the classroom implementation, the inconsistency of translation to the classroom may well have been due, at least in part, to constraints impacting teachers' ability to reproduce their lab experiences in the context of a K-12 classroom. For Joshua, curricular constraints prevented him from drawing upon the content related to his research experience. In relating her research experience to the classroom, Sarah had to reconcile the material resources available to her in the classroom with those that she used in her research, thereby shifting the focus of her curricular unit to work within such constraints. Ryan appeared to be the most adept at translating his agential intra-actions into a classroom-appropriate version for his students. This could have been influenced by a number of factors, including his extensive 32-year teaching experience, the context in which he taught (i.e., a well-equipped private school), and/or the alignment of his courses with the focus of his research placement. Indeed, it is possible that Ryan's engineering course naturally lent itself to exploration of such a vast array of material given the breadth of content that he deemed relevant to the course, from the physiological basis of Parkinson's disease to the mechanics and clinical applications of medical imaging. In comparison, Sarah and Joshua addressed content linked more traditionally to their courses (i.e., bone structure and development for Sarah's anatomy and physiology class, physics of elasticity for Joshua's physics class) despite the fact that both approached these topics through the lens of a clinical problem or issue.

As Barad (2003) noted, "On an agential realist account, discursive practices are not human-based activities but rather specific material (re)configurings of the world through which local determinations of boundaries, properties, and meanings are differentially enacted" (p. 828). Due to a number of factors as described above, Ryan's instruction appeared to be subject to fewer curricular boundaries, which may have provided a more robust ground for the (re)configuration of meaning through his students' agential intra-actions during classroom instruction. This suggests that further research is needed to explore what structures and/or resources need to be in place to support agential intra-action in K-12 settings most effectively. Meanwhile, in order to more fully immerse teachers and students in the practices of science and engineering as called for in the NGSS, the role of including agential intra-action as described by Barad must be made explicit both in teacher research experiences and the classroom.

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