Manual-technical operations: Hands-on science as necessary but not sufficient

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Abstract

The importance of culture and social interactions in disciplinary learning and language development within specific social practices and contexts is now an agreed-upon notion in the science education literature. In a pivotal article in 1990, Lemke introduced the idea of manual-technical operations as one of four modes making up the "hybrid language of science". Our aim in this paper is to further unpack the concept of manual-technical operations as a mode, thereby contributing to the more complex understanding of when and how this mode enhances meaning-making and communication of ideas. Drawing from researchers in diverse disciplines, we present a visual of the complex and integrated manual-technical operations mode. It is our hope that the theoretical model proposed in this manuscript will allow researchers to develop analytic frameworks to capture and assess change in the manual-technical operations mode of the hybrid language of science.

Key words: hybrid language, manual-technical operations,

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Introduction

The importance of culture and social interactions in disciplinary learning and language development within specific social practices and contexts is now an agreed-upon notion in the science education literature (Moore, Evnitskay, & Ramos-de Robles, 2017). Much of this research has its roots in sociocultural constructivist theory (Vygotsky, 1978, 1986), situated learning theory (Lave & Wenger, 1991; McLellan, 1996) and semiotic theory (Bezemer & Kress, 2016; Kress, 2010). From these theoretical stances, the particular discourse of the science community is seen as embedded in the natural world of science practices and only makes sense within the social and physical setting that surrounds this community. Meaning-making and communication are part of a collective social history which includes all tools developed by the group. The use of the tools of the culture provides learners with opportunity to acquire the discourse (language and practices of science) while they explore natural phenomena. As Rogoff (1990) states, "learning occurs through guided participation in social activity with companions who support and stretch understanding of and skill in using the tools of the culture" (p. vii).

The social activities resulting in acquiring citizenship in the science community require learners to integrate "language, actions, interactions, ways of thinking, believing, valuing, and using various symbols, tools and objects to enact a particular sort of socially recognizable identity" (Gee, 2011, p. 29). Learners must become comfortable with multiple "types of representational systems and practices" (Gee, 2004, p. 13) and use "language in sync with or in coordination with other people and with various objects ('props') in appropriate locations and at appropriate times" (Gee, 2011, p. 31). If students are to become enculturated into science, they must engage in actions that are seen as socially acceptable and needed.

In a pivotal article, Lemke (1990) stresses that "we construct systems of meaning by using language, mathematics, diagrams, and techniques. They are our social tools, and they differ from one social community to another" (p. 185). Later he states that in science, this includes "the ability to make meaning conjointly with verbal concepts, mathematical relationships, visual representations, and manual-technical operations" (2004, p. 38). This notion of a unique hybrid was especially titillating when introduced to the science education community because it enhanced and extended the limited idea of language as consisting only of reading, writing, listening, and speaking as studied by linguists (Koster, 1987; Lyons, 1991). At the same time, Lemke's framework of four modes provided an excellent launching pad for thinking about the importance of manual-technical operations as a mode of the language of science.

A review of the literature provides evidence of science education research about natural language (Brown & Ryoo, 2008; Cervetti, Barber, Dorph, Pearson & Goldschmidt, 2012; Fang, Lamme, & Pringle, 2006; Lee, 2005), mathematical expression (Olivares, 1996; Osterholm, 2005), visual representations (Bowen & Roth, 2005; Bowen, Roth & McGinn, 1999; Friel, Curcio, & Bright, 2001; Roth, 2002; Tytler & Hubber, 2016) and manual-technical operations (Roth & Lawless, 2002; Siry, Ziegler, & Max, 2012). However, we are left wanting to interrogate more thoroughly the mode of manual-technical operations as a language mode. Our aim in this paper is to further unpack the concept of manual-technical operations as first defined by Lemke (1998, 2004). We argue that this mode of hybrid language not only contributes to a more complex understanding of the meaning-making of scientific ideas but such an understanding has direct implication for curriculum design and pedagogic practices. It has the potential of moving teaching beyond superficial hands-on experience to scaffolding manual-technical operations as an avenue to support meaning-making of the science ideas.

Unpacking Lemke's Manual-Technical Operations

Science educators are thinking more critically about modes of language and how they foster competence for meaning-making. For us, Lemke's influential and pivotal work captures the intricate system of communication as he proposed the language of science as a hybrid with four distinct, but interlocking and complimentary, modes. In much of the science education research, language has been theorized as both the mechanism and the medium for learning. However, three modes of the hybrid language proposed by Lemke—natural language, mathematical expressions, and visual representations—have garnished more attention than manual-technical operations. We find that the notion of manual-technical operations remains comparatively underdeveloped and may be confused with hands-on or activity-based science instruction. In fact, only a few studies have sought to unpack and deconstruct the mode of manual-technical operations within the science classroom and, yet, manipulations of physical tools are an important part of meaning-making and communicating science ideas and cultural norms.

In thinking about the role of manual-technical operations, we first reviewed the science education literature. Although we found a corpus of research about embodied choreographies, facial expressions, and gestures, we focus on 'doing science' (Siry et al., 2012) in taking a direct route of thinking about the three terms (manual, technical, operations) as selected by Lemke. When used as an adjective, *manual* means of or done with the hands. (This rules out facial expressions and gestures[1], although an important area to study.) *Technical* refers to specialized tools as recognized within a community. *Operations* denotes the active process involved in meaning-making in science.

We, therefore, posit that this language mode must have a tool that is operated (to some degree) by hand[2] in ways that make or communicate meaning. This leads us to distinguishing between manipulation and movement when describing manual-technical operations. Manipulation requires skillful control of a tool; whereas, movement also includes gestures and expressions. The manipulation of tools is part of the existing culture of science disciplines that uses natural phenomena that can be re-enacted in classrooms. This re-enactment helps entrench the norms and discourse of the science discipline. The physical process or situated action may take many forms from donning particular safety gear to the operation of highly specific tools.

Although there is a long history advocating hands-on activity, real-world knowledge, and laboratory-based exercise, the corpus of research varies as to the emphasis on and description of the action and appropriation of tools within a science class and its function in meaning-making. Huxley stated "[I]n teaching him botany, he must handle the plants and dissect the flower for himself…Don't be satisfied with telling him that a magnet attracts iron. Let him see that it does; let him feel the pull of the one upon the other" (1899, p. 127). Similarly, Dewey reminded us that while experience is needed, not all experiences are educative. He states '[I]t is not enough to insist upon the necessity of experience, nor even of activity in experience. Everything depends upon the quality of the experience which is had" (1938, p. 27). Real-world knowledge was advocated by DeGarmo (1895) when he stated that teachers should "recognize that our education succeeds just to the extent that we make it focus upon the real activities of life" (p. 241). In 1920, the National Education Association stated, "the pupil should go to the laboratory to find out by experiment some facts that are essential to the solution of his problem, and that cannot be obtained at first hand by other means" (p. 53).

More recently, De Landa (2006) posits that tools and manipulations come in various iterations and combinations but are always embedded in practice. This idea is expanded by Siry, Ziegler, and Max (2012) as they state that during multimodal experiences "understandings are continually evolving through participation in interactions around science phenomena" (p. 332). Thus, for scientific purposes, manipulation of technical tools is necessary as part of a complex process of meaning-making. When thinking about pedagogic practices, science teachers must move beyond episodic hands-on activities to systematic infusion of manual-technical operations

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[1] See the work of Wolff-Michael Roth and colleagues for information at embodiment

[2] We recognize that newer digital technologies may remove direct hand contact

that supports knowledge production within the sociocultural context of the classroom. This involves iterative use of tools in the context of scientific discovery to aid in meaning-making.

Our concept of manual-technical operations reflects the belief that this mode of the hybrid language of science is, itself, multi-dimensional. Pulling from the literature, we stress the embeddedness of three critical dimensions (manipulation, context, and technical tools) within situated meaning-making. We further stress that each component is equally important as part of the discipline of science, but that at any moment the relative weight shifts along intersecting continua, as we will explain below.

Situated and Contextualized Meaning-making

Meaning-making, from a sociocultural viewpoint, involves a relationship between an individual and an environment (Gee, 2008; Van Der Veer & Valsiner, 1993). The environment/ situation/ context intertwine in ways that provide the learner with affordances or action possibilities (Lave & Wenger, 1991). Meaning is made as the individual integrates new information into existing schema. This can be at the individual level, as posited by Piaget (1926, 1972), or community level, as posited by Vygotsky (1978, 1986). For sociocultural constructivists, the socializing that happens in communities creates meta-knowledge by fusing interpretations, values, and culture.

The context is highly important as seen by Vygotsky's differentiation between spontaneous and scientific concepts. For him, "scientific concepts originate in the structured activity of classroom instruction and impose on the child more formal abstractions and more logically defined concepts than those constructed spontaneously" (Fosnot & Perry, 2005, p. 22). Vygotsky tries to help readers understand that meaning-making is complex and requires the interweaving of formal and informal experiences. The experience provides space for meaning-making within the mode of manual-technical operations to occur through the interplay of manipulation, context, and tools. In theorizing about learning, Vygotsky stresses the importance of language, highlighting that language has two functions: "(1) a means of social coordination of the actions of various people; and (2) a tool of thinking" (Van De Veer & Valsiner, 1993, p. 57)
Similarly, manipulation may be completed with an audience present thereby involving public meaning-making. On the converse, in manual-technical operations the manipulation of a tool may be executed without an audience; therefore, the meaning-making piece may be private. As a mode of hybrid language, concepts are created and undergo change as students continue to engage in manual-technical operations within the community or alone.

From a social semiotic viewpoint, the environment is instrumental in having an effect in shaping the learning and communication. Current research builds on the work of Halliday (1978) who argued that grammar (natural language) should be seen as "a resource for making meaning (p. 192). Van Leeuwen (2005) extends the use of 'grammar' beyond natural language to include other semiotic modes. Historically, these resources were called 'signs'; for example, "a frown would be a sign of disapproval, the color red a sign of danger" (Van Leeuwen, 2005, p. 3). Social semiotic resources have "potential constituted by past uses that are known to and considered relevant by the users" (p. 4) and the focus is on the way individuals use sign/symbol resources to interpret artifacts and events (make-meaning) and to communicate meaning to others.

Therefore, in manual-technical operations, the manipulation of the scientific tools within the context of inquiry-based investigations is a communicative, meaning-making 'sign'. The following graphic (Figure 1) illustrates the complexity and interdependency of the components as tools (complex to simple), manipulation (gross to fine motor), and context (highly specialized context and everyday context) are embedded within the cognitive aspect of meaning-making. The dots serve to represent the relations of the three as they interact. A position within the multidimensional planes is fluid since a person can have a highly specific proficiency of manual-technical operations in one discipline of science and yet have less proficiency of a manual-technical operation in another, unfamiliar domain.

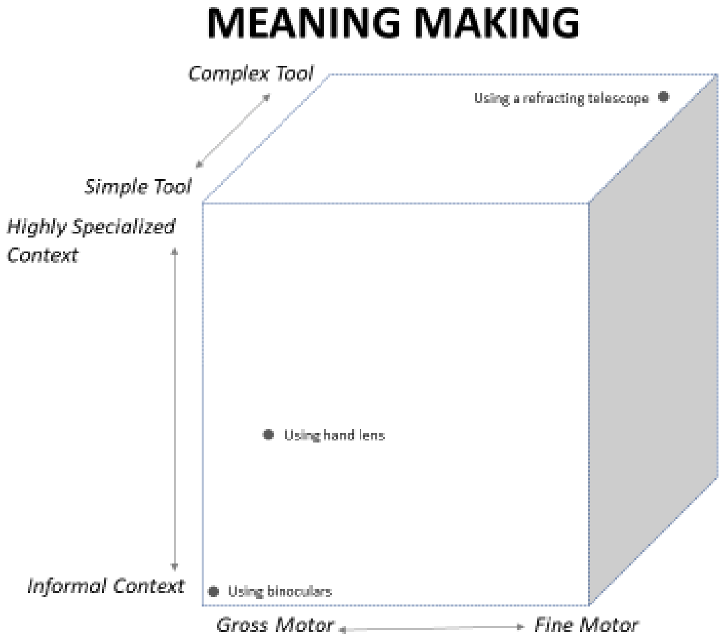

Figure 1. The three dimensions situated within the meaning-making cube interact to create points of intersections as shown by the dots. Using magnification as an example, the points show different intersections of the three dimensions.

In the first example we position a hand lens such as the one typically used in elementary classroom. The hand lens is not usually used in informal settings but is not highly specialized either, thus it is shown partway along the context continuum. In addition, because it is small but not highly complicated, it requires some fine motor coordination, thus we position it partway along the motor continuum. We use another simple tool such binoculars at sporting events in a second example. In this example, the context axis reflects the informal situations (e.g. sporting events) in which this magnification tool is used. The manipulation axis reflects the gross motor skills needed to use a set of binoculars. This example is at the simple tool end of the axis bringing it to the front of the cube. The third example (refracting telescope) illustrates all dimensions at their extreme ends of the continuam. This manual-technical operation example uses a highly contextualized, complex tool requiring fine motor skills. Each 'dot' moves along the continuum with individuals as learning takes place.

Manipulation

Movement is a necessary part of learning and thinking (Blakemore, 2003). The ability to grasp and use hands in conjunction with tools is considered a major accomplishment for human beings and changes with human age. Van Der Veer and Valsiner (1993), in outlining influences on Vygotsky, describe the work of Engles on the origin of *Homo sapiens* in which Engles posits that "erect posture freed the hands for the manipulation of objects" (p. 197). This, in turn, provided for "the hands, sense organs, and brain [to] develop in a complex interaction" (p. 197). This emphasis on the relationship of the body (manipulation) and mind (learning) continued in Vygotsky's work as he sought to understand how cultural tools are used in meaning-making and communication.

In understanding the significance of the body in learning, we draw on the work of Merleau-Ponty (1962) who used the term 'habit' to denote the "knowledge in the hands, which is forthcoming only when bodily effort is made" (p. 144) as he refuted the Cartesian mind-body dualism. He argued that "what can be known via bodily experience, while often incapable of being expressed in words, is known at a deeper level" (Juntunen & Hyvonen, 2004, p. 200). In line with this is Polanyi's (1966) notion of tacit knowledge which suggests that embodied knowledge is often hard to verbalize or describe but is manifested in pre-reflective actions. Tacit knowledge is evident when the action is internalized to the degree that it become invisible to the actor.

Much of work in exploring the natural world in science is accomplished through the fluid, repetitive manipulation of existing laboratory/field equipment. The skillful manipulation of a tool distinguishes members from non-members of the lab. If the practice is new or unfamiliar to the student, it moves to the foreground and often takes concentration and is not fluid. However, as a student becomes more adept at using the tools, thinking about the practice moves to the background with the manipulation becoming routine (or tacit knowledge), freeing the mind for other tasks. Although new ways of manipulation are developed on a regular basis for research laboratories, in K-12 science classrooms, students learn standard manipulation as already agreed upon by the science community.

The ability to manipulate tools changes with age and experience. Muscle development is described as ranging from large muscle bundle control (i.e., gross motor) to control of small muscle fibers (i.e., fine motor). As infants mature, they refine their ability to coordinate muscle bundles which results in more complex physical tasks. The coordination of the muscles of the hands begins with flexing the fingers and progresses to grabbing objects. At first the objects are large and the hand movements are jerky and unrefined. However, with time and physical development, the hands become able to accomplish very refined and precise movements in informal contexts. A three-year old child might be given large blocks and plastic measuring cups to accommodate the lack of fine motor skills. The materials used by the child during science exploration become smaller and more precise as fine motor skills are honed.

Several examples of how manipulation changes over time serve to illustrate our point. Measuring the mass of different objects is a practice common in science classrooms. In early manipulation that result in knowing the measure, the child uses gram stackers with the double-pan balance which relies on gross movement rather than fine movement. Later, the child is introduced to the triple-beam balance that requires the fine movement of sliding the marker along the beam to give a more precise measurement while losing the direct connection to balancing items. Moving alone the continuum, other more complex manipulation is seen when using a Mettler Balance which is even more abstract.

Another example of how manipulation changes over time comes from a three-week video observations of students as they manipulated a model—a stream table with sand--to test variables effecting erosion on a hill. Of particular note was the change in how quickly the students were able to collect the appropriate materials and assemble the ‘base-line model’. Each assembly of the ‘base-line’ included massing the amount of sand to put in a stream table and positioning the sand at the correct depth and length to create a slope (Figure 2). In the beginning the students concentrated and talked about how to set up the materials. By the last day, their improved manual-technical operations allowed them to assemble the materials while conversing about what they predicted would happen as they changed the next variable. This is an example of how fluency in manual-technical operations decreases the cognitive load enabling students to focus on and foreground the science concept. Thus we stress the continuum as seen in Figure 1 on the X-axis as motor coordination becomes more refined.

Figure 2. Students quickly setting up the ‘base-line’ slope in order to test the variable of hard rain on the hill.

Context

Many researchers have pointed out the importance of context for learning. In science, the context for understanding natural phenomenon often includes experiences, objects, and other participants. The idea of learning as a social activity was highlighted by the early research in situated learning and communities of practice. In stressing the importance of the context/ situation, Lave and Wenger (1998) wrote that learning "may well have more to do with legitimacy of participation…than with knowledge transmission…Learning to become a legitimate participant in the community involves learning how to talk (and be silent) in the manner of full participants" (p. 105). Being a full participant only occurs as the individual within a community of practice interacts in a space or context.

Context is not limited to the formal environment of school. Everyday experiences provide context for understanding the world. We think of the 'informal' context as places such as the post office, grocery store, department store, and gas station where science is 'happening' and parents or care-givers might take children on a regular basis. These experiences might include packages falling from the counter (gravity) at home, produce rotting (decomposition) at the grocery store, and electricity discharging while replacing clothing (static electricity) at the laundry mat. The science is often not 'visible" because these experiences are so familiar and not explicitly pointed out by a more knowledgably other as a natural phenomenon.

Moving along the continuum, field trips and outdoor opportunities create real-life situations in which informal meaning-making can occur. We think of the informal (but not everyday) context as places such as museums, zoos, and other areas where science is 'happening' and which children occasionally visit. In these places, the child has the opportunity of reading signs and watching videos which present scientific information but often has little manual-technical operation opportunities. The science may be more evident here than in everyday places but frequently is not well articulated for children and not well understood.

Typically, children then move into more formal science contexts such as the classroom and other instructional environments. Within these socially mediated contexts, novices manipulate the tools as means of understanding and communicating in science. Simultaneously, students are scaffolded into the use the other modes of hybrid language - academic discourse of natural language, mathematical expressions, and visual representations. As students move through more complex places, such as a high school chemistry or biology classroom, they find context clues in specifically designed desktops, inclusion of eye-wash stations, and specialized tools.

The inter-connectedness of manual-technical operations is reinforced as both the tool and its manipulation are affected and dictated by the context. In the context of a Kindergarten or 1st grade classroom gram stackers and large blocks would be a typical tool. For an upper elementary classroom, the context would provide more specialized equipment such as a triple-beam balance, hot plate, and model of a stream table. At the high school level, each discipline (chemistry, biology, physics) would have a room designed specifically for that subject matter. The types of tables and the specific tools (hoods, roto-vac, beakers, dissecting trays, force/motion apparatus) depict the discipline and the growing specialization of the curriculum.

This inter-connectedness was evident with high school students in a chemistry summer program on a university campus. Students were immersed in a working laboratory (context) in which they were conducting original research with a well-known chemistry professor. Evidence from observations (video of laboratory time) indicates that students quickly became proficient in the setting of a college laboratory (Figure 3). The context that was once intimidating (e.g., hood, wash station, confined spaces, specific disposal methods, and storage of materials) became comfortable to navigate.

Figure 3. The context of a chemistry lab makes the clothing and tools appropriate.

Tools

Tools, developed over time for specific functions, are very important in the learning by community members. Many of the classical science tools are still in use today by researchers, technicians, and teachers even as new tools are invented. These tools are important items within the social environments as they help make sense of the natural phenomenon.

At home or in the early grades, students are encouraged to ‘play’ with items that can be described as ‘simple tool’ such as blocks (friction, center of gravity, size, shape), water tables (sinking/floating, buoyancy, properties of liquid), and costumes (identity, safety). Materials found in the kitchen (can openers and strainers) help develop ideas such as simple machines making work easier and of large objects being filtered or removed. These tools, combined with informal language (hot/cold and big/small), set the stage for more sophisticated ideas and complex tools to come. We acknowledge that the sophistication of tools increases with the complexity of the job.

Later, elementary science classes introduce children to basic, standardized, measuring instruments (thermometers, beakers, balance, rulers). At this level, however, chemical materials tend to consist of baking soda and food dye used in ways that are not typical of a kitchen experience. Goggles and aprons become safety tools within these contexts.

As with context and manipulation, middle and high school tools become increasingly refined as the science disciplines require more specific instrumentation for labs and experimentation. The task indicates the necessary form of the tool as well as the tool dictating the function that can be done. Measuring moves toward digital technologies that allow for very precise calculations (digital thermometers, scales, computers and probes, lasers). Materials incorporate more chemicals that are special ordered from supply catalogs instead of bought off a grocery shelf. Organisms found in this context include stained slides and dissection specimens. Safety equipment also becomes more refined with the addition of fire blankets, eyewash stations, and disposable gloves.

An example of a refined manipulation of a tool was captured on video as part of a research study with eighth grade students from an urban district who participated in a CSI unit. Several tests were conducted with evidence from the ‘crime scene’. DNA samples were separated using electrophoresis, which required moving small samples from vials to the wells in the DNA chamber (Figure 4). The students learned to become more adept and confident with pipetting. Part of being recognized as a member of the scientific community is the ability to use the tools correctly and with confidence.

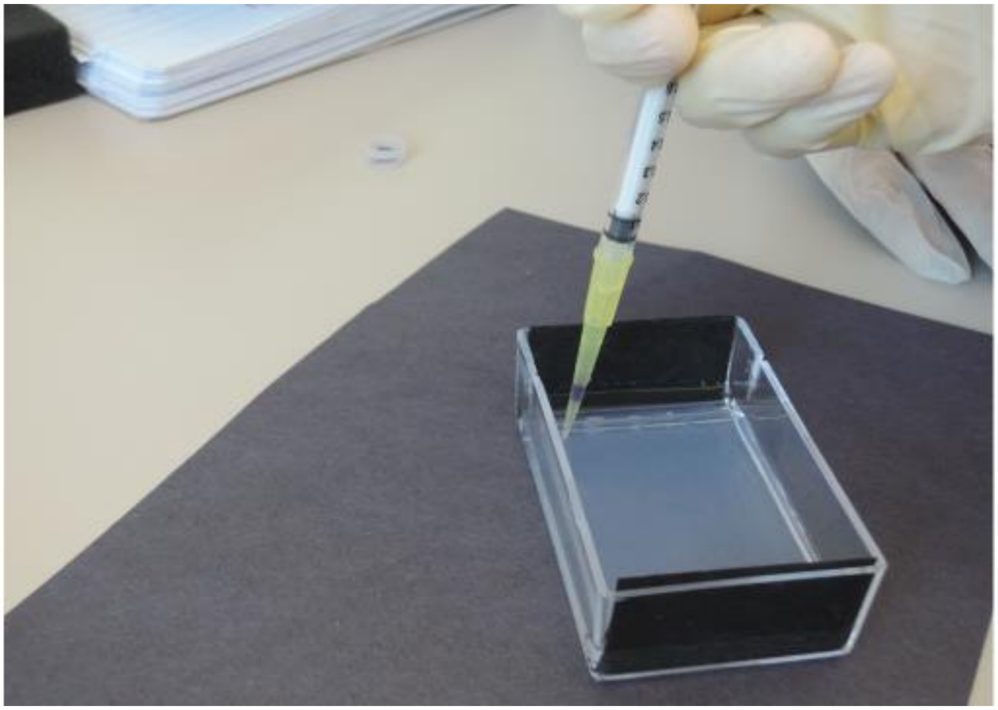

Figure 4. Student using a pipette to put a DNA sample in the well of a gel for electrophoresis

Theory into Practice: A Case Study

To further explore the ideas presented above, we examine a class of 11th grade students engaged in a chemistry investigation in which a liquid mixture needs to be separated. The overarching goal is for the students to communicate their knowledge of characteristics of liquid mixtures and use of lab materials while building their understanding of evaporation/condensation and characteristics of matter.

The context for the event is a high school chemistry lab. The lab is a culturally derived institution within science with this lab having a unique set of norms and values that generate from the district, school, teacher, and students. The lab design symbolizes the district/school/teacher educational philosophy with set fume-hoods, access to water, fixed work stations, student-accessible storage, and teacher-only storage. This ‘formal’ educational space is restricted to students taking advanced science courses.

The students were provided with tools: lab aprons, gloves, safety glasses, Erlenmeyer or round-bottom flasks, ring stands, plastic tubing, thermometer, glass tubing, hotplate, and 1 and 2-hold stoppers for the flask. These tools reflect the socially constructed understanding of distillation and lab safety. Each tool is rather generic until they are assembled to make the distillation apparatus. The apparatus communicates an understanding of different boiling points as a way to systematically separate liquids. It also communicates that the capture of the liquid requires the condensation (thus cooling) of the vapor. The addition of a thermometer allows for the recording of boiling points for different materials. Students in the chemistry class are able to assemble the apparatus because they have experience with the tools and know their use.

Within the context and using the tools provided, the students conduct the labor of or planned action that uses hand-eye coordination, fine motor skills, and practiced skills. Their movements are fluid and they set up the ring-stand and round-bottom flask, as this is a manipulation that they have done several times. However, the movements become less coordinated as they prepare the ‘cold water bath’ for the condensation tube. They understand the reason for cooling the vapor but have not performed this assembly before.

Implications for Curriculum

Although tools, movements, and contexts are found ubiquitously in life, they must interact in unique ways to be considered as the manual-technical operational mode of the hybrid language of science. Manual-technical operations are necessary to build understandings and communicate the vast complexities of science concepts. When this mode of hybrid language is absent or lacks fluency, breakdowns in understanding may occur. Furthermore, manual-technical operations become more fluid with exposure and determined practice. By recognizing the value of the manual-technical operational mode of hybrid language, science teachers and curriculum designers who want students to be fluent in the discourse of science understand that it means that students must be equally fluent in manual-technical operations. This requires that the learner be exposed to the manipulation of tools as often as possible and in conjunction with the opportunity to use natural language, mathematical expression, and visual representation. Positioning manual-technical operations as a meaning making resource within science has implications for the inclusion of this mode within the science curriculum. We offer curriculum implications for the inclusion of manual-technical operations in the science classroom.

Understanding that manual-technical operations contribute to the construction of meaning within the context of the science classroom requires that we further consider the role of hands experiences within the science classroom. Hands-on science experiences serve to provide the beginning building blocks for manipulating tools within the context of exploring natural phenomena in the classroom, yet, these experiences, though necessary, are not sufficient. While students often encounter other modes of the hybrid language as independent subjects (language arts, mathematics, visual art), proficiency in manual-technical operations can only emerge when explicitly scaffolded within the context of these hands-on explorations of natural phenomena. Such scaffolds must provide students with opportunities to engage in activities to support cognitive and metacognitive awareness (Dignath & Büttner, 2008).

Research in other disciplines (e.g., second language acquisition) has a solid history documenting cognitive and metacognitive awareness in language and learning (Bunch, Walqui & Kibler, 2015; Chamot & O'Malley, 1987, 1996; Gibbons, 2006; Hakuta & Santos, 2012; Hammond & Gibbons, 2005). Consistent with this view, teachers systematically embed in the curriculum explicit opportunities for students to plan, monitor, evaluate and reflect on new learnings and understandings. The language acquisition literature also provides evidence that students who recognize the functions and forms of these disciplines are more proficient second language users. Therefore, it is reasonable to state that form and function recognition along with the ability to talk about these forms and functions are necessary in the development of manual-technical operational proficiency. It follows that when teachers explicitly introduce the idea that form follows function and talk about their use, they support meta-awareness of manual-technical operations through reflection. For example, teachers build such an awareness as they consciously help students become mindful that their eyesight is not good enough to see small object and that magnification is needed. As students are made aware that the function of lenses is for magnification (e.g., specialized tool), they must understand and reflect that some forms of lenses (single or multiple) better serve a particular need. When the object to be viewed is small but is not microscopic, a single lens is appropriate. However, for highly microscopic or very distant objects, versions of multiple lenses are needed. Thus, to develop awareness of what tool suits the context, students must actually handle the lenses. Lastly, teachers must support students in developing meta-awareness of these forms and functions. This points to the teachers' role in helping the students know about and develop skill in manual-technical operations.

Curriculum planners must move away from a simple notion of 'hands-on' to a notion of meaning-making through manual-technical operations. They should also think about how to provide a necessary scaffolded gateway toward greater fluency within manual-technical operations. Working in collaborative groups, pairing with more experienced students, or even tutoring from a teacher comprise many ways this scaffolding occurs. The manual-technical operational mode cannot be fully developed without the use of scientific tools as part of science discovery. As stated above, a single encounter with manual-technical operations is not sufficient; rather systematic, multiple encounters are needed. When applied to curriculum planning, this requires thinking of all the opportunities for repeating the uses of tools introduced earlier. For example, after scales are introduced and used in an early experience, teachers must continue to offer the opportunity to use and reflect about the use of scales within subsequent labs. This is consistent with the notion that students need multiple opportunities to use all modes of language in order to recognize how can be used in different ways to express similar ideas (Gibbons, 2006; Lemke, 1990). Knowing that time is always a factor in planning, not building in multiple encounters with manual-technical operations limits the student's ability to develop this mode of the hybrid language critical to scientific discourse.

The ideas presented above are significant to both teachers and curriculum planners in a time of testing and the desire for transmitting facts and correct answers. Manual-technical operations can easily be overlooked when thought of as only hands-on. It becomes background noise if it is not explicitly pointed out and its meaning-making potential acknowledged. But when teachers become aware of this as a meaning-making mode, they can foreground it and mine its potential. Moving forward from the notion of hands-on activity to a notion of manual-technical operations as an integral part of the discourse of science positions this mode of the hybrid language as a critical part of the curriculum.

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