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Interviewing: An Insider's Insight into Learning

Marc S. Schwartz
University of Texas

Kurt W. Fischer
Harvard University Graduate School of Education

Abstract Interviewing is often thought of as a research tool, but by shifting focus, teachers can use "interviewing" to support two important classroom goals: clarifying student understanding, and in turn providing students with opportunities to organize more meaningful structures of understanding. We provide an operational definition for levels of understanding and a hierarchical framework (similar to Robbie Case's developmental framework) for evaluating changes in student understanding during the interview process.

From a very different perspective, the student's insights are viewed from the brain's central organizational principle; brains learn about patterns in the world in order to make reliable predictions about its environment. Thus, new insights are new patterns that students recognize and can test against reality within carefully constructed classroom activities or during the interview process. Pattern recognition and changes in neural activity offer an additional dimension for understanding the dynamic interaction between the teacher/interviewer and student, which we also explore in detail.

Introduction

Interviewing is often thought of as a research tool, but by shifting focus, teachers can use "interviewing" to support two important classroom goals: clarifying student understanding, and in turn providing students with opportunities to organize more meaningful structures of understanding. Skill theory (Fischer 1980; Fischer and Bidell 2006) provides an operational definition for levels of understanding (i.e., skills) and a hierarchical framework for evaluating changes in student understanding during the interview process, and this approach has much in common with the developmental framework of Robbie Case (1985, 1991). Specifically the chapter explores, through several conversations between a student and her science teacher, how the interview process can highlight and support a range of skill levels representing all or part of the student's "zone of proximal development" or ZPD (Vygotsky 1962; Vygotsky 1978).

From a very different perspective, the student's insights can be understood in terms of the brain's central organizational principle; brains learn about patterns in the world in order to make reliable predictions about its environment (Mountcastle 1998). Thus, new insights are new patterns that students recognize and can test against reality within carefully constructed classroom activities or during the interview process. Furthermore, as the brain matures it follows a pattern of change in neural activity that is hypothesized to support the emergence of new stages and levels (Case 1992; Fischer and Rose 1998). These changes support the ability to detect richer patterns and solve more complex problems. Thus pattern recognition and changes in neural activity offer an additional dimension for understanding the dynamic interaction between the teacher/interviewer and student, which this chapter will explore in detail.

Overview: Change Over Time

A significant challenge for educators is evaluating student understanding as they participate in classroom activities. Students also face a similar challenge as they confront or explore the depth and integrity of their knowledge. At the intersection of both tasks is one process that can help both teachers and students. The interview can help teachers recognize, represent and evaluate student understanding. The same process can empower students to better appreciate and confront their views.

Change in skills

How students organize and capitalize upon their observations and ideas can be thought of as a strategy or a “skill” (Fischer 1980; Fischer and Bidell 2006). However an important feature of skills for researchers and educators is that they capture the organizational complexity of student understanding and action. More importantly skills that students use to solve problems or make sense of their world are never fixed. They can vary in complexity depending on context and/or the type and degree of support they receive; thus, student abilities can vary along a range similar to what Vygotsky (1962; 1978) characterized as the Zone of Proximal Development or ZPD. This “zone” represents the difference between how students perform when solving problems alone versus solving problems with the support of more capable individuals. “It is the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers” (1978, p. 86). Because the interview can support changes in student understanding, we will examine in greater detail how this process impacts one student’s effort to understand a classroom problem, and how this effort impacts the skill level she uses.

Changes in brain activity

Changes in student understanding as measured by changes in skill level can also be viewed from the perspective of the brain. One of its key general functions is to identify patterns in the environment and compare them with stored memories of older patterns in order to detect changes, and if necessary, make predictions about future events or the success of a specific response (should one be necessary) (Hawkins and Blakeslee 2004). When the environment changes, even in minimal ways, the challenge the brain faces is whether it will detect the difference(s) and be able to respond if necessary.

Another important change in brain activity occurs over a longer time frame as children mature. The brain's progress in its own development limits the complexity of patterns it can detect or entertain and the skill that can be coordinated. For example, changes in neural architecture underlie the initial development of coordinated action in infants, later speech in toddlers, and, in adolescents, the emergence of formal reasoning. Underlying each of these new abilities are reciprocal changes in brain activity across brain regions, which enhance brain function.

These brain-based changes will occasionally enter the main story to enhance our understanding of the dynamic relationship between skills and context as illustrated through the dialogue between Eve and her science teacher. At a visible level of analysis, the interview will highlight the variables Eve is considering as she looks for meaningful patterns, and re-organizes and coordinates experiences, ideas and memories into new predictions and new skills (or in educational terms, possible solutions). Eve is 12 years old and studying electromagnets. To follow the evolution in her ideas, we first outline skill theory as a theoretical framework for analyzing with greater precision Eve's progress in integrating ideas and experiences throughout the interview. In a later section, "*Exploring the Process,*" we focus on Eve's journey within the interview while highlighting important features of the teacher's role. The theoretical framework reappears throughout this section as a means of helping the reader compare and contrast changes in the student's perspective and to consider the role that the brain plays in supporting these changes. In a later part of this section, the content of the dialogue helps illustrate the scaffolding power of the interview process and its potentially important role in curriculum development.

The site for change – the classroom

Educators create problems and activities for students by presenting or highlighting specific aspects of the environment they want students to consider. Students in turn discover the relevant pattern that serves as a framework to guide them in selecting and coordinating ideas and actions into a skill that serves as a response. The skill also represents the student's prediction of what best counts as an answer. Eve is about to have her first experience with electromagnets. Her ideas and questions provide not only an intimate picture of her understanding, but also reveal how students her age make sense of electricity and electromagnets (Shipstone 1985; Schwartz 2000; Schwartz and Fischer 2004). Her teacher sets the stage by building a simple but functional electromagnet made of easily recognizable materials– a 12-penny nail with 20 wraps of wire (see Figure 1). The wire is 80 centimeters long. Each end is stripped and attached to one end of a battery.

[Insert Figure 1 here]

The teacher then demonstrates that his prototype lifts one, maybe two links of a chain. Students are offered the opportunity to inspect the teacher's design for several minutes before he presents the following challenge: "Can you improve the electromagnet so that it will pick up more links?" The challenge is carefully worded to encourage students to explore electromagnetism by providing a goal that allows them to capitalize on strategies that seem plausible and variables that seem relevant (e.g., increase the number of wraps, use a larger nail, or add layers of coils).

From the perspective of neuroscience this challenge is a natural opportunity for the brain to do what it does best– compare external patterns (i.e., observations of the environment) and internal patterns (i.e., memories) of the way the world works (or is expected to work), and try to align them to reduce conflict and/or generate solutions (Hawkins and Blakeslee 2004). The brain searches for relevant memories about the world, and tries to apply them to this new context. As it turns out, children and adults rarely refuse the opportunity to test out their predictions and will work with great intensity and focus to see if their predictions are correct (Schwartz and Sadler 2007). They add wraps of wire around the nail; change the location of the wraps, the number of nails, or the size of the nail. After each change they measure the strength of their latest design by counting the links of chain they can lift with their electromagnet.

Within the first hour of experimenting, Eve's teacher recognizes that students can improve their electromagnets. Students quickly realize that by adding more wraps or moving the wraps closer to one of the ends of the nail, they can increase the strength of their electromagnet. But how would they explain the relationship between these changes and the results they noted? Do new patterns of understanding emerge from such an activity, and if so, are they meaningful to the student?

Theoretical Framework

When students arrive at school they also come with personal ideas about how the world works (Hugh and Novak 1983; Driver, Guesne et al. 1985). These views signify important personal achievements in creating meaning out of the enormous amount of information that nature, schools, parents, friends, and the media provide. Student explanations often reflect some degree of internal consistency, account for variability in a phenomenon, and are well thought-out. Consequently these views are often highly resistant to change through instruction (Driver, Squires et al. 1994; Sadler 1998).

As this chapter will explore, interviews that focus on the student's experiences can help them question their ideas and support new understandings. However, recognizing the importance of these scaffolded conversations is difficult in traditional education because student achievement is often defined in terms of what students accomplish on their own. In contrast, Vygotsky (1978) offers a broader and more powerful view of achievement:

> "It is generally assumed that only those things that children can do on their own are indicative of mental abilities. ... even the profoundest thinkers never questioned the assumptions; they never entertained the notion that what children can do with the assistance of others might be in some sense even more indicative of their mental development than what they can do alone" (pg. 85).

This difference between what students can do alone versus what they can accomplish with support can be described with even further precision with skill theory (Fischer and Pipp 1984). In this model of cognitive development, students can operate at multiple skill levels depending on the degree and quality of support they experience, with the highest level established in part by the extent of the biological development of their cognitive capacity.

By viewing student achievement as a function of support, teachers have an opportunity to re-evaluate as well as redefine their roles in student-teacher interactions. The interview process is one such opportunity. By focusing on the structures students use to organize their experiences and ideas, students find that they have the opportunity to better define how they are thinking about a problem or experience. When students are not sure what they understand, the student-teacher dialogue allows students to construct a personal view. Students who are conscious of their structure of understanding can more easily recognize ideas they want to challenge, change, or abandon when confronting new problems and/or observations. This kind of focused dialogue facilitates the student’s progress toward their "potential level of development" (Vygotsky 1978).

Teachers also benefit when shifting their focus from teaching to the purposeful attention that the interview generates. To the extent that the dialogue succeeds in revealing the student's framework of understanding, the teacher can clarify the student's actual (or functional) developmental level and evaluate the student’s success in moving toward his or her potential level of development. The actual level is the foundation upon which future learning is built, and a necessary insight that prepares teachers for the task of building and targeting lessons that challenge student views and in turn support growth to more sophisticated structures of understanding.

When Eve explores her ideas in an interview, so that they can make sense to both her and her teacher, Eve has the opportunity to clarify partly formed ideas and to integrate them into tentative structures for making sense of her world. Together Eve and her teacher discover or retrace paths, as necessary, to understand Eve's evolving view of electromagnetism. The teacher keeps track of and makes available to Eve her experiences and ideas when she feels lost or disoriented. This action facilitates their exploration of her structure of understanding, and indirectly supports changes in student understanding even though this is not the goal of the interview.

During such interchanges students will often sense a growing clarity in their ideas, which motivates them to stay engaged in the dialogue. However, again, the goal is not to “teach”. The goal is to attain a complete picture of the student’s world and the patterns they recognize as pertinent to making sense of their experiences. The work often feels satisfying to the student because the conversation is focused on their understanding; and, any change in understanding is the student’s creation.

Skill Theory: Developing more complex structures of understanding

As Eve's general ability to detect more nuanced patterns and coordinate ever more complex skills evolve through maturity and experience, skill theory offers a hierarchical scale of development for describing and evaluating her progress both in the short term as she navigates between her functional and optimal level and in the long term as additional and more powerful levels and tiers emerge as a result of maturation (Fischer, 1980; Case, 1992; Fischer and Bidell, 2006). Progress is measured as changes in “skill” levels. Operationally, skills highlight the complexity of understanding that emerges from the dynamic interaction between the individual’s developmental progress (an outcome of maturity) and context; and thus, a skill level captures the degree of complexity in our ability to act or respond as we mature and/or as contexts change.

Skills are hierarchical in nature and, at the largest level of analysis, are grouped into four tiers that unfold during human development (reflex, action, representation, and abstraction). (This analysis has much in common with that of Case, 1991, although there are also important differences.) In each tier the individual displays a new ability that encompasses the successes of earlier tiers. Each tier is a fundamentally new way of understanding the world. In the first tier babies demonstrate a set of *reflexes* that allow them to immediately respond to the world. These innate skills become the platform for the development of a set of *actions* the infant develops to allow her to interact with the world (instead of just respond in an automatic fashion). This new tier, the second, enables her to respond and interact with her world in more complex ways such as grabbing items of interest. As toddlers become children the action tier in turn become a platform that supports the emergence of a third tier, *representations*. In this new tier she can create symbolic understandings about her world that substitute for the sensorimotor experience. A striking ability that emerges in this tier is the ability to use words to represent actions (e.g., walking, drinking, laugh, cry, etc.). The pattern of encompassing and building upon earlier achievements repeats itself again in early adolescence when children becomes developmentally ready to use representations to create a fourth tier of understanding– *abstractions*. Figure 2 illustrates the cascade of skills growing in complexity beginning with the second tier (sometimes called the *sensorimotor* tier).

[Insert Figure 2 here]

When students enter school they are developmentally ready to create and organize understandings in the third tier (i.e., representations); however, having reached this developmental milestone does not insure that they will understand the representations they encounter in school. Because skills are context specific, the transfer of representations from teachers and books to students is often a difficult and unsuccessful process (Salomon and Perkins 1989; Pea 1993; Nardi 1996). "Skills are not automatically or easily generalized or integrated. Consequently, even when people have skills appropriate for a task, they frequently fail to use the skills and thereby function below the level required by the task" (Fischer, Bullock et al. 1993) (pg. 92).

In order to help students develop more complex skills, teachers not only need to recognize where students begin their learning process (i.e., their actual developmental level), but also understand that the nature and degree of support they offer plays an important role in the skills students use as contexts change. A closer inspection of the representational tier and the types of representations Eve (and students like her) creates, reveals smaller incremental *levels* of development or understanding that increase in sophistication within the tier.

Within each tier there are four intermediate levels, which provide a finer grain view of development or understanding. Each level is a more complex structure (and therefore a new skill) that demonstrates further coordination and integration of earlier levels. In the representational tier the four levels are single representations, mappings of representations, systems of representations, and systems of systems. Additionally, the last level of a tier is unique in that it supports the qualitatively new way of knowing that is the beginning of the next tier and thus creates the first level of the new tier (Fischer and Bidell 2006). Thus by combining the four tiers and the four levels within each tier the developmental framework can be portrayed as a 13-level developmental scale. (Note that the total number of levels is 13 instead of 16, because the last level of each tier is also the first level of the next tier. Furthermore the levels of interest in this chapter and in school learning in general begin with the first level of the action tier- See Figure 2.)

Although the 13 levels that emerge over 30 years of maturation mark developmental milestones, they do not emerge in a continuous, uninterrupted metronomic march from one level to the next. While the metaphor of a staircase for development and its associated analogy of progress, as in climbing up the stairs, are common (Case 1991), both are misleading. Even though the trend in development is toward increased complexity over the long term, in the short-term progress is more unpredictable (for example when confronting a new problem) and often looks more like one step up and two steps back. This observed discontinuity in progress was previously thought to be the result of error in the tools used to measure change, but when studied through dynamic models the noticeable instability appears to be one of the prominent properties of progress (Fischer and Bidell, 2006; Van Geert 1994; Thelen and Smith 1998).

Ultimately maturity in the long term (and support in the short term) contributes to individuals operating at "higher" and thus more complex levels (using the stairs metaphor); however, a more nuanced view of development requires looking more closely at the discontinuities in shorter time frames such as during problem solving. At this level of analysis, the spurts and discontinuities observed in the short term highlight a prominent phenomenon when observing growth in both behavioral and neurological terms. In terms of behavior, progress is sensitive to context (to include support and/or scaffolding). In terms of brain growth, we see the same influence of a dynamic environment on the progress the brain makes in supporting the emergence of more complex skills.

A hypothesis for how the brain supports the emergence of new skill levels

As just highlighted, a central phenomenon when observing growth (both behaviorally and neurologically) is the presence of discontinuities. Behaviorally, discontinuities are observed in the fluctuations between optimal and functional skill levels as individuals are developing and learning to generalize optimal skill levels to new contexts. Optimal skills are at the cutting edge of a person's ability, and thus their stability and longevity is highly influenced by context (including support) and scaffolding. In a parallel fashion, discontinuities in brain activity help highlight important changes in the organization of the brain that are hypothesized to underlie the emergence of skill levels observed as individuals mature.

However, the link between brain and behavior is often not direct or obvious. Some connections are continuous while others display discontinuities over time. Dynamic modeling can help uncover order within variability when trying to understand the nature of discontinuities (Van Geert 1994; Thelen and Smith 1998). Just as progress in behavior can spurt forward, collapse or halt as contexts change, discontinuities in the brain's electrical activity provide clues about how the brain is developing.

Two important metrics for evaluating changes in brain activity are coherence and relative power. Both are determined from electroencephalogram (EEG) readings of electrical brain waves. While coherence is a correlation of wave patterns in different cortical regions, power is a measure of work being done by the neurons over time (or simply, energy expended by neurons). Both measures provide clues on how changes in the neural architecture may be supporting skill development.

Relative power in brain activity measures the relative amount of power used by different regions of the brain. When looking at how the brain distributes energy over time, an important initial observation is the surge in power in the prefrontal cortex as new tiers emerge. This initial surge is also followed by peaks in power in different areas of the brain, which may mark the emergence of the intermediate levels within the tier. During the time that development within a tier is occurring there is the opportunity for the general skill typified by the tier to diversify and grow in complexity through the four levels embedded in the tier.

In a concurrent manner the brain appears to be consolidating the robustness of each level. Nested within the power surge is an additional pattern of coordination occurring between different regions of the brain. This coordination is measured through coherence. Specifically, when regions of the brain are communicating with each other, resulting electrical wave patterns in each region are highly correlated, and thus coherence is high. In this case, the regions of importance are the prefrontal cortex and the other major lobes (parietal, temporal, occipital and the central area of the brain). Although the pathways are numerous, the coherence between regions has been studied in a systematic way revealing a striking pattern involving the prefrontal cortex and the remaining regions (Thatcher 1994). A compelling hypothesis is that a discontinuity in wave patterns preceding any observed increase in coherence between the prefrontal cortex and each of the remaining regions signifies the incorporation of additional networks to support a specific level (Fischer and Bidell 2006). Furthermore, the emergence of each new level requires the coordination of existing skills at the current skill level, which the prefrontal cortex is responsible for orchestrating.

Thus one hypothesis is that the emergence of tiers and levels follow an increase in relative power measured at specific sites. An additional hypothesis is that consolidation of each level is enhanced through communication, measured in coherence, between the prefrontal cortex and each of the other major areas of the brain. This pattern repeats itself over time as each tier develops. Thus discontinuities (as a theme) not only underscore the emergence of skill levels but of neuronal activity. While the emergence of optimal skills during problem solving depends on environmental support, support within the brain appears to build upon a redistribution of energy, which increases the power at specific sites in the brain (Fischer and Bidell 2006; Fischer and Rose 1998). Both coherence and relative power underscore how neuroscience is building a more complete picture of what we observe behaviorally.

A closer look at the skills that unfold for students like Eve

The first level of the representational tier is a one-dimensional view or understanding of the world. For example, a single representational skill for electromagnets is the name for the “wire-nail-battery ensemble” – an electromagnet (Schwartz 2000). When one’s understanding is confined to this skill level, variations along any dimension (size of nail, number of wraps, the quality of connection between the wraps and the battery) are not obviously important unless they are extreme (i.e., more or less wraps would not matter, but wraps should be visually obvious) (Schwartz and Fischer 2004).

Young children, two or three years old, easily demonstrate the power of this singularity. If they hold the basic view of electromagnets as a device that attracts objects, they will repeatedly try to pick up a variety of objects without noticing a pattern in what electromagnets do and do not attract. As long as the ensemble parts are present, the electromagnet should attract objects. Furthermore, if the electromagnet ceases to function, they would be unable to diagnose the problem. However, despite the obvious limitations in this level of understanding, the single representation is the foundation of the representational tier, and serves as the building block for more complex representations.

As students mature, their ability to recognize features (as potential variables) of a single representation improves. For example, they might conclude that the number of wraps influences the strength of the electromagnet. This new emergent skill, which is called a "mapping" of two representations (level Rp2), allows children to coordinate variations in a single dimension of interest such that changes in this variable lead to changes in the single representation. Metaphors often work at this level in that they reflect an understanding about relationships observed in the world (Lakoff and Johnson 1980). For example, the metaphor "more is better" supports students concluding that more wraps would lead to a stronger electromagnet. Without failure, the first change that most students suggest in order to improve the strength of their electromagnet is to increase the number of wraps (Schwartz and Sadler 2007). Analogies are similar to metaphors in that they offer students linear relationships that help them make sense of one specific aspect of their experiences. A limitation of representational mappings is that they only support a smaller range of predictions about the world. This skill often demonstrates a focus on the impact of only one variable as these student examples illustrate:

- Increasing the wraps will increase the strength of the electromagnet
- Moving the wraps closer to the head of the nail will increase the strength of the electromagnet
- Using a bigger nail as a core will make the electromagnet stronger

Over the longer term, as students continue to mature they become developmentally prepared to challenge metaphors or mappings. Even though students in Eve's class are developmentally ready to challenge their mappings, for many students this emerging skill is closer to their optimal level, thus they will need support. When examining more closely the connections between their explanations and their observations, they may recognize weaknesses in their metaphors and analogies. Prior to any experimentation, these simpler models provided quick explanations or predictions, but did not account for other observations or variables under inspection. To address the increased complexity needed in coordinating more variables, a more complex skill is necessary.

In skill theory when individuals can successfully coordinate two mappings they are using a more sophisticated skill – at the level of representational systems (Rp3). Here the coordination of two mappings allows the student to consider how several observations and metaphors work at the same time. When students become more comfortable integrating new observations and ideas with their original metaphors, they are better able to entertain more sophisticated models of understanding. This skill is illustrated by the following comments or realizations:

- The strength of the electromagnet varies with both the placement of wraps and the number of wraps
- The strength of the electromagnet varies with both the number of wraps and the size of the core

As models for understanding electromagnets become more sophisticated (and approach the structures of understanding that scientists typically use to understand problems they are studying) students can account for additional variables, provide more accurate predictions, and/or extend their understanding of established mappings to additional contexts.

Sophisticated models like the field theory of electromagnetism require the coordination of multiple representational systems (Rp3) involving both electricity and magnetism. With further practice, experience, and maturity this new level of coordination can become internalized as an abstraction (Ab1). In this new tier, understanding transcends the physical, observable, concrete nature of representations. Hypothetically students could enter this tier of abstraction by recognizing the concept of "fields" as a phenomenon that both electricity and magnets create. The field's shape and density can be defined in real terms, but understanding the nature of its existence requires that one transcend the many physical variables that lead to its creation. Developmentally, Eve and her classmates have the potential of achieving this first level abstraction, but more time, support and practice would be necessary before their understanding in this tier emerges. Actual examples did not appear for Eve and her classmates. (Table 1 summarizes the evolution of skills concerning electromagnets from Level Rp1 through Ab1.)

Ultimately the conversation with Eve (or any student) will reveal a particular range of understanding within skill theory’s 13-level scale of developmental complexity. In this case, Eve makes extensive use of skill levels within both the sensorimotor and representational tiers. Initially Eve used skills at her functional level to understand electromagnets, but the dialogue with her teacher began to hint at her potential to use more sophisticated levels. These optimal levels were at the leading edge of her development, laid down through the maturation process; however as of yet, Eve may not have encountered classroom contexts where this potential ability could emerge. As Vygotsky (1978) suggested, students are not bound to any one level. They can move to higher or lower levels as Eve demonstrates during the interview process.

This process of interviewing may sound instructional, but the teacher's goal during this process is only to understand her students’ views even though this particular focus can support students coordinating more complex skills. Students are most likely unable to maintain this level on their own, thus the conversation highlights the skills students one day will organize on their own, and the kind of work necessary by the teacher and curriculum to support this transition.

Exploring the Process: Eve and Her Teacher’s Journey

Eve and students in her class had few problems creating single representations of electromagnets. Students recognized pictures of electromagnets as long as it included the right components: wire, battery, and a core (see Figure 1). However students at this level of understanding (Rp1 single representations) do not yet appreciate that the number and placement of wraps matter, that opposite ends of the wire must be connected to opposite ends of the battery, that the core should be iron, etc. When students are able to coordinate these variables in order to create a richer understanding of electromagnets they are demonstrating progress towards the next level in the representational tier (i.e., mappings at Level Rp2)

For many students, their first step towards this more sophisticated view of electromagnets takes shape around what they know about plumbing (Shipstone 1985; Schwartz and Fischer 2004). The plumbing model of electromagnetism is not only straightforward; it is effective. Eve sees the wires somewhat like pipes in which water or electricity flows. Pipes keep the contents within the walls just as the insulation should hold the electricity until it arrives at its destination. Her teacher, Mr. M, discovers as well as supports Eve's construction of this model early in their interchange:

M: What comes to mind when you hear the word electromagnet?

E: Well… at least something that works like a magnet but it generates electricity.

M: It works like a magnet but generates electricity...

E: Like... sort of, it could be like in (pause) ... I think it could be saying: electricity could run through…

At this point Eve is unsure what she thinks about electromagnets; however, Mr. M encourages her to develop her thoughts by prompting Eve with just one word:

M: Something... (Eve picks up the prompt and continues.)

E: Like electricity could run through it...

M: Yah...

E: ...to connect to something else.

M: Electricity could run through it to connect to something else...

E: Like in a cord.

M: So you imagine electricity passing through the cord, and then what happens?

Mr. M summarizes Eve's thinking to provide her the chance to hear what her ideas sound like, as well as offer her the opportunity to agree or change his summary. The teacher wants Eve to know that he is attempting to follow her thoughts and that she is still free to develop or explore related ideas with him.

E: Uhm, I heard that there are electromagnets in telephones. They could be going through the cord and connecting... uhm (pause)... like when one piece of energy to another.

M: I think I see. So your idea is that electricity is passing through the cord and it's connecting one object… (Mr. M is interrupted.)

E: to another

Mr. M doesn't know what "one piece of energy" means to Eve, but recognizes her focus on "connections". He suspects that Eve is using the plumbing model, but still invites her to modify his interpretation of her ideas by restating her thought about "connecting " and by qualifying his summary with, "I think I see." Eve's growing comfort and attention in this conversation is evident at the end of the last interchange when she interrupts Mr. M and completes his sentence.

The interchange continues with a sharper focus on the details of Eve's understanding of electromagnets:

M: ok… I see. Do you think this electromagnet has any properties... things it does or doesn't do?

E: Well it is made of metal. And it probably... needs to be insulated, if you're using it. But I've never experimented with one.

The potential role of the plumbing model reappears in Eve's observation that electromagnets need to be insulated. Incidentally, this model survives well into adulthood because, for the most part, it works well in most contexts (Shipstone 1985). Improving this model would require an understanding of complete circuits. Most adults recognize the importance of complete circuits, but they are not always successful in coordinating that understanding with their "plumbing" metaphor (Schwartz and Fischer 2004). A representational system (Rp3) illustrates the potential coordination of these two relevant ideas: (1) electricity flows through a medium, and (2) circuits of any kind only work when the circuit is complete.

Mr. M temporarily ends the interview so that Eve can continue building an electromagnet that she thinks will outperform the teacher's. When the interchange continues a few days later, Mr. M will have several questions in mind. Did experimenting help her recognize that there are problems with her plumbing model? Is she ready to look for more sophisticated strategies to account for her observations? Together Eve and her teacher will define and navigate the transition from beliefs (or simple models) towards more sophisticated models of understanding. To ensure that Eve recognizes what she believes, her teacher begins by exploring Eve's beliefs to understand them as she does. He avoids explanations or opportunities to correct mistakes to avoid disturbing Eve's focus on her beliefs. In this opening exchange Mr. M invites Eve to continue exploring with him her progress in making sense of electromagnets:

M: Do you remember what you were saying about electromagnets a few days back?

Eve: Uhm, I thought it was something that carried electricity... and through one object to another...it sort of... I just thought it sort of connected two things because it was magnetic and it also carried electricity through it, energy.

M: So what do you think now?

Eve: Well I thought.... I think... Well we haven't really experimented with it [the electromagnet]. We only saw how powerful it was and I'd like to try... while it's picking up a chain... I'd like to put a magnet near it. See if it will throw off the [electromagnet]... see if it will throw off the course.

Mr. M invites Eve to think out loud with him in order to continue their exploration in discovering the layout and boundaries of Eve's world of understanding. During their last conversation Eve mentioned that a permanent magnet might affect an electromagnet. Mr. M recognizes that the interaction between permanent magnets and electromagnets is an important issue for Eve. He takes her lead and investigates Eve's progress in making sense of her observations and experiments:

M: I remember last time you saying that if you brought a permanent magnet next to the electromagnet it might throw it off.

Eve: Yah, and I haven't tried that yet.

Eve has not yet resolved this problem; however, Mr. M does not want to discourage her from returning to the problem if she wishes. He does not judge Eve's ideas or her decision not to investigate her magnet-electromagnet hypothesis. Because there are no results to explore, Mr. M uses an open-ended question to re-launch his investigation of her progress:

M: Maybe, you'll be able to try that later. You'll have some time. So how do you think the electromagnet works?

Eve: I think... it probably... uhm, the electricity... the wire is carrying electricity and it is touching the nail as well and while it [the electricity] is circling really, really fast around the nail [through the wraps], the nail sort of builds up (pause) like very strong…. (pause) Maybe some of that electricity goes into the nail.

As Eve approaches the end of her description she senses a problem with her plumbing model. How can electricity leave the insulated wire? A few days earlier Eve observed that when the wire was hooked to the battery the nail became magnetized. How did this happen? She recognized that the wire was insulated and that insulation prevented electricity from escaping and, as she will consider later, electrocuting people. From her point of view the electricity has to leave the wire and enter the nail in order to magnetize the nail. What her plumbing model can't explain is how the electricity can leave the wire in order to enter the nail. This understanding is deeply rooted in the sensorimotor experience of containers where liquids cannot escape unless the container has lost its integrity. Once she concedes that electricity may be entering the nail, her model of electricity is vulnerable to change. Eve recognizes the significance of this new relationship as she attempts to coordinate new ideas with older ideas, a foundation for change that Ausubel (1968) recognized as a precursor to developing new understandings. This re-organization process underscores how the brain looks for relevant memories to make sense of new observations in order to create a pattern that leads to reliable predictions.

Thus, the conversation not only clarifies Eve's skill level, but it also supports her effort in creating more complex skills to account for her observations. Eve's teacher can later consider the kinds of follow-on lessons that would best support Eve's continued progress in working at her optimal (or potential) level of development. However, for the moment, the pair remains focused on exploring how well Eve's models work in the real world, and what options are available when they encounter problems with making reasonable or accurate predictions. Eve has not yet recognized all the problems that exist with her model. Much later she will pose the question, "How does electricity get into the nail if the wire is insulated?" Eve needs more time to clarify the problems she faces when using her mapping skill (i.e., the plumbing model) to make sense of her experiences, and to explore, coordinate, and integrate observations and ideas in the face of those problems.

Mr. M maintains his attention on Eve's construction process as well as her conclusions. This attention allows her to build a picture of electromagnets where she integrates and coordinates details she might not have considered unless she was trying to articulate her picture with a partner. The interaction with Eve is analogous to how Phillips (1988) describes Winnicott's use of mirroring in psychoanalysis. The psychiatrist gives back to the client what the client brings to the relationship. In this way the client discovers feelings he does not recognize until they are reflected back to him. The process has the same effect on students. Eve discovers her thoughts and feelings about her work when her teacher gives form to her ideas. The degree to which Mr. M can accurately mirror Eve's ideas contributes to their shared understanding of electromagnets and Eve's ability to challenge the patterns she sees.

Once the image of Eve's present understanding of electromagnets takes shape, and both Mr. M and Eve can agree on the details in the pattern she sees, the teacher can accentuate the mirroring process by focusing on Eve's choice of verbs, analogies, or expressions. What are the consequences of these choices in her attempt to understand electromagnets? He focuses on those elements to explore any deeper understanding, mysteries, or confusion. To this end, he returns specifically to her use of the verb "building" when describing what happens to the nail:

M: What "builds" [up] in the nail?

Eve: Like a lot of power because there's, there's like energy and electricity running, like right around it, everywhere.

M: around it, around...

Eve: the nail, and when I tried putting the wire all the way around the nail, almost covering the entire nail, it [the electromagnet] was really powerful because like… all that… there was so much force going around that nail.

Mr. M helps Eve organize her world by keeping track of what she sees and keeping them available to her as a mirror does when you look into it. Because it is difficult to focus on all parts of the image that a mirror provides, Mr. M brings to focus elements that might be worth examining. His choice of elements can be influenced by what he knows about electromagnets, but can also be influenced by elements that seem to be important to Eve. However, again, his goal is not for Eve to guess what answers or insights he has (which would shift the focus from Eve to her teacher), but to recognize the opportunity for seeing new patterns or different aspects of an existing pattern with an experienced traveler in a new world we can call "Electromagnet Land".

Not only does the interview process help Eve recognize the consequences or implications of her views, it can also reveal places (in Electromagnet Land) where she becomes disoriented. Feeling disoriented is typical when examining a new subject from a new perspective. This is akin to being disoriented in a familiar but rarely visited part of town; you might know that you are not far from home, but not quite sure how to connect "where you are" to "where you want to go." The brain is searching for relevant patterns or a shift in focus that will allow a pattern to emerge. A bird's eye view of the terrain would help, but is only possible for the teacher at this time. So he challenges Eve to focus on those areas where the terrain is still unclear and her points of reference do not yet help. Again, this thorough investigation of Eve's understanding creates opportunities for encountering and thinking about problems they encounter. Eve and Mr. M arrive at such a problem in the following interchange:

Eve: I think that (pause).... what I'd like to know is if you hold an electromagnet too long... uhm, it… it's going to start to burn and if... I don't know how, but if they use it [electromagnets] in telephones. I'd like to know how they use it without it getting overheated.

M: Yah, that's a good question.

Eve: And having something melt, because I saw that happening with the electromagnets. [Her team had observed that if the electromagnet remains connected to the battery for too much time, enough heat is generated to melt the insulation around the wire.[1]]

M: What do you think was happening there?

Eve: Uhm, I think the battery was... was bringing in too much power, the battery became really hot and the plastic around it starting melting and that electromagnet has to have a battery or a source. It has to sit somewhere.

M: Uh huh

[1] Even though this experience allowed Eve to encounter an interesting relationship, Mr. M decided to use C size batteries instead of D batteries in later lessons, which generates much less heat.

Eve: And if it overheats I'd like to know how they get it [the electromagnets] in ... Uh, like not overheated, because if a telephone is plugged into the wall, it has an electromagnet somewhere in it that has electricity running through it. There's if... if, I think if you unplug it, the telephone... uhm, it's going, it's going... like turn off the electromagnet and not let it overheat (pause), but the only way for a telephone to work is when it is plugged in.

M: It seems odd to you that the phone is always plugged in and still it doesn't overheat?

Eve has stepped out of a familiar environment and sees a problem with an old pattern about how telephones work (i.e., they are plugged into wall sockets, they contain electromagnets, but they don't get hot). As she considers her new knowledge, which comes from building and testing electromagnets with her peers, Eve may realize that she is in an unfamiliar place in terms of her understanding of telephones. She has observed electromagnets overheating in the past. This experience creates a strong, highly organized skill within the sensorimotor tier, which is easily observed in students gingerly touching an electromagnet if they know it has been connected to a battery. Eve knows that phones contain electromagnets, and that there is a lot of electricity available at an electrical outlet. So what keeps the phone from overheating? Eve is at an impasse. She has difficulty organizing and interpreting her observations, especially when she tries to make sense of them to her teacher. She might wonder how far this new conceptual landmark (seeing electromagnets overheat) is from where she was before she embarked on this voyage (recognizing that phones use electromagnets). Is there a bridge that will close the gap she perceives here?

Naturally, a teacher would be tempted to provide an explanation to close the gap; however, explanations that come too quickly still have risks that we will explore in the next section. The interview process is still powerful enough to support the teacher and Eve in recognizing and capitalizing on opportunities to scaffold new ideas and uncover potential blind alleys, roundabouts, etc. Furthermore, the teacher's continued exploration will contribute to the lessons he designs later to challenge and support the types of problems students identify during these types of conversations. The conversation highlights the patterns of understanding students hold and what kinds of feedback might be necessary in follow-on lessons that could help direct the student's attention.

Interviewing as Scaffolding

Scaffolding, as its image might suggest, is the framework that holds an unfinished building or idea together. Scaffolding is the teacher's attempt to keep the student engaged with the problem, to limit the number of tasks needed to solve a problem in order to ensure the child can reach a solution, and to control frustration by making "problem solving less dangerous or stressful with a tutor than without" (Wood, Bruner et al. 1976). The interview provides Eve the scaffolding to help her integrate the patterns that a trained eye sees in nature (like her teacher's) with the patterns that her brain is trying to detect. This effort has but one goal– to help her predict what she might see when she looks into Electromagnet Land. For example, in the following interchange Eve introduces many ideas about how to make an electromagnet stronger, but Mr. M takes only one at a time.

Eve: Because I know that sometimes the wire gets loose [the wraps around the nail], the wire goes in different directions [making for a sloppy looking electromagnet]. I think that they are probably going [to] use like, thicker wire and have it a little more powerful.... and a lot more powerful battery. Because in this case it [the telephone and the electromagnets inside] is plugged into the wall. And that has a lot more electricity going through it. So it [the phone's electromagnet] is probably more powerful.

M: Uh huh. So you think neatness is important as well, because you mentioned that...?

Eve: Yah, because every single piece of wire has to touch the nail... like I think to make a complete circuit around it.

There are a number of variables that Eve is considering: neatness, thickness of wire, the amount of electricity available, and, her latest thought, complete circuits. For example where does neatness fit in her exploration of Electromagnet Land? This new mapping (Rp2) suggests that Eve may be trying to coordinate both neatness of wraps (which contributes to the wires ability to maintain contact with the nail) and electromagnet strength. She also seems to be trying to coordinate the "neatness-strength" mapping with another involving a second variable (i.e., thickness of wire) and its impact on the electromagnet's strength. In this case, a coordination of these two mappings would represent a new representational system (Level Rp3); however, nature's response to Eve's tentative system would be that this more complex coordination is not a pattern nature recognizes.

The interchange is also open to investigating what she means by a "complete circuit." In the last exchange, Eve was weighing the impact of neatness, thickness of wire, and complete circuits as variables; and, their importance in electromagnets do differ. The pattern is complex, and Eve needs to consider and weigh all the variables to recognize the pattern that leads to the most powerful predictions. Mr. M recognizes that some explorations will provide more insight than others, but may not be able to tell which path will be the most promising; however, he remains patient. Their investigation doesn't have to start or stop with neatness, but does have to begin somewhere.

By choosing to investigate any one variable with Eve, her teacher is also scaffolding the process scientists use to discover the importance of variables embedded in the patterns observed in nature. All disciplines have developed ways of knowing that teachers bring to their conversations with students. In many cases, that process is only obvious to the teacher. Even though the student is still in charge, her attention is being focused in a manner scientists would recognize. The conversation temporarily assumes the structure of a controlled experiment, where Mr. M explores the power each variable has for Eve. In follow-on conversations, Eve and Mr. M might investigate additional relationships between her ideas; discovering the dead ends in her map of Electromagnet Land, the roads that intersect, or the roads that run parallel to each other. Her teacher helps Eve keep track of her explorations, her findings, and her success in creating more sophisticated skills to coordinate her ideas and discoveries.

Given the variety of possible directions the conversation might take, Mr. M recognizes that of all the variables, one in particular resonates with the plumbing mapping, which dominated the earlier conversations. His close attention to Eve's progress allows him to recognize that an important element of neatness is Eve's concern that the wire touches the nail. The new "neatness-strength" mapping reveals her attempt to bridge what she knows about plumbing to what she has experienced with her electromagnet.

M: Oh, I see. You think the wire has to touch the nail?

Eve: Yah, touch the nail.

M: So if we wrapped the nail with paper for example... and then... wrap the paper and the nail with the wire. Do you think that would work?

Eve: Well, it depends. I think that electricity might be able to go through paper, but not like really thick surfaces.

M: All right... let's say... Oh I see, not "thick surfaces".

Eve: Yah, because I think it could [go] through paper, but not something really thick... like a piece of wood.

M: So you think the electricity leaves the wire and actually goes into the nail?

Eve: Yah

If her plumbing model of electricity holds, then the wire must touch the nail and the electricity must somehow leak into the nail. But electricity will not leak into the nail; yet, according to her mapping it must. Mr. M remains silent at this point to let Eve consider the problem she has encountered with her plumbing model. Eve is encouraged to continue her thinking, and as a result she encounters a problem that is perfectly reasonable considering her present working model. After a few seconds Eve asks, "What I would like to know is if the wire is insulated, how does it [the electricity] get into it [the nail]?"

Eve arrives at the question that began crystallizing earlier with her acknowledgement that maybe some of the electricity enters the nail. Mr. M still resists offering an explanation. More importantly, Eve is not really asking Mr. M to answer the question, so he doesn't. He is also conscious of the trap science educators (and possibly all educators) encounter to by assuming that their first responsibility is to offer students more sophisticated models as replacements for their ideas. Teachers find it difficult to resist the temptation to demonstrate the way they solve problems even though educators have long observed that students rarely use their teacher's models (Holt 1964; Bredderman 1983; Driver, Guesne et al. 1985; Schneps and Sadler 1988; Miller 1992; Lightman and Sadler 1993; Driver, Squires et al. 1994; Shamos 1995; Barker 1999).

Students more often defer to the simpler models, metaphors or beliefs they have created when trying to make sense of a problem (Novak and Gowin 1984). Eve demonstrates the power of the plumbing model to make sense of her question regarding insulation:

Eve: … I think, like [the electromagnets] might be less powerful. Very little [electricity] is escaping into it [the nail] no matter how many links [of chain] we think it [our electromagnet] picks up. Because it could be uhm, that... uhm, it [our electromagnet] is less powerful, for us not to get electrocuted. But inside a telephone it's all covered and everything. So they probably do it [use wire] without the insulation. Because then they wouldn't have to worry about anyone touching it [the wire and getting electrocuted].

M: Ah, so you think if you took apart a telephone, and you saw an electromagnet, the wires wouldn't have any insulation?

Eve: Yah. Because there's no risk of anyone getting electrocuted. In this case [with the electromagnets we are making], I think that very little [electricity] is escaping into the nail.

Eve is still weighing the usefulness of the plumbing mapping. She is reasoning that the battery was not powerful enough to allow electricity to cross the wire-nail divide. She feels that this issue would not be a problem with more electricity (as an electrical outlet could provide) and wires that had no insulation (such as she suspects exists in telephones). Mr. M continues to explore with Eve the usefulness of the metaphor because it is clear that this mapping captures an important pattern that she sees in nature (i.e., in order for objects to get from one place to another a conduit is essential). Wires do allow the electricity to travel, much in the same way that pipes transports water. This metaphor is still a useful skill for interpreting events. Accordingly, Eve concludes if the wire is not insulated, then the electricity will be able to leave the wire and move to the core. However Eve still needs to confront the limits of this pattern (characterized during much of this text as a representational mapping or, more generally, as the plumbing metaphor).

The focus on insulation and the need for contact between the nail and wire has lead to a new scenario, which Eve created. In this new context Eve is empowered to take specific action to test a specific prediction. Eve's new state of mind is also underscored by the minor theme of this chapter– the role the brain plays in this process. Its ongoing goal is to identify possible patterns in order to make more reliable predictions. Eve will find out, when she takes apart the phone, that the wire used in the electromagnets is insulated. How will Eve react to this discovery? It will not match her prediction. What will she say when she discovers that all electromagnets use insulated wire, and when all the insulation is removed, the electromagnet stops working?

Eve is at the cusp of organizing a new representational system (Level Rp3) that accounts for how insulation and conduits contribute to electromagnetism. The plumbing metaphor she uses to represent reality is an intermediate level of understanding of the world that will support more sophisticated models. Once again it is important to recognize that metaphors are important structures for making sense of reality (Lakoff and Johnson 1980). They help bridge the gap from the known to the unknown.

This path to more sophisticated models (which in this text has often meant, “more complex skills”) will be supported by her investigation of phones because this test addresses a problem Eve recognizes with the plumbing metaphor. The outcome is difficult to predict. She may ignore the evidence that electromagnets use insulated wire, and continue trying to use the plumbing model. She may modify the plumbing model by focusing on other relevant observations. There is also the risk that she may realize this model doesn’t work and abandon electromagnetism in complete frustration. The margin between frustration and empowerment is one that the teacher must attempt to moderate. With the help of her science teacher, Eve (as well as her classmates) may be ready to consider the idea of “fields” and take a step towards an important abstraction (arising from coordinating several representational systems at Level Rp3) in electromagnetism. Eve has already noted that magnetism can impact certain objects without physically touching the object. Further consideration of this phenomenon moves her closer to a system of systems that describes both electricity and magnetism in terms of “fields”.

This fields abstraction (Level Ab1) assumes that electricity passing through wires sets up an invisible field much in the same way that magnets set up an invisible field. Eve played with permanent magnets in an earlier lesson, and observed that magnets can influence certain objects as at a distance. Water, passing through pipes, cannot do this, but electricity in wires can. Recognizing this new “mapping” represents an important step in integrating it with more established mappings in order to construct a key representational system (Rp3) that coordinates ideas such as conduits, influence over space, and insulation. This coordination is a step towards the more complicated model of field theory.

Scaffolding: a constructivist's view

Could the electricity running through a wire generate a field that affects the nail? The answer is yes, and careful lesson planning can help prepare students for this transition in understanding; however, by rushing to the answer educators risk not appreciating that the trip from "naive model" to "sophisticated model" represents critical steps in the evolution and development of more complex skills. Just offering Eve the destination does not offer her a way to find the connections between what she already understands and what science education tells her she ought to understand.

Scaffolding an exploration of electromagnets through the interview process supports the constructivist position that students must build their own meaning of concepts, and in science as in most subjects, this requires time, time and more time. The teacher's role is to facilitate that construction with both focused questions and lessons that the student appreciates and understands. Using Eve's description of electricity is very useful from a constructivist point of view. Educators begin with what Eve knows, using the language that she uses to understand electricity. For example, Eve explains the importance of "big" (and a related metaphor) in building stronger electromagnets in the following way:
Eve: I haven't experimented with big nails, but if it's really big like in a laboratory, scientists use really big powerful instruments. They'd probably find that if they use really thick wire and a really big nail, a lot [of electricity] will circulate through that nail. I think that's probably the second most important thing.

In Eve's comment we can still observe the importance of the plumbing model as she suggests that "really thick wire" can carry a lot of electricity. This insight makes sense if you believe that a big pipe can carry a lot of water. Here again is another opportunity for her to test her model against reality. Are there additional areas of reality for which her model does or does not account? Nature's patterns are revealed through closer and closer inspection of the world. But how far can the teacher support the student in this exploration? Without being certain of the answer for Eve or any student, the teacher offers a context that allows Eve the room to grow comfortable with her ideas so that she can begin to see where they hold and do not hold.

Eve would need to decide if she wants to invest the energy in creating a new more comprehensive model or simply ignore all the problems this investigation and conversation raises. Can the brain get tired looking for patterns? People often face this issue when confronting a problem where the old paradigm or model has been shown not to work. They know at some point they will have to expend time and energy to modify or replace the model that they have been using. It might be reasonable to expect that the resistance to changing a model is directly related to the time and energy necessary in creating a better model along with the new circuits required to support this new view. In any case, schools should serve to help Eve and her peers challenge their own views. Unfortunately too many students enter adulthood without having had the opportunity to seriously challenge any of their own models.

Conclusions

This chapter ends where most teachers want it to begin. Mr. M is satisfied that he understands Eve's construction of the world of electromagnets, and Eve is satisfied that she has made some progress in understanding through her own initiative; however, clearly there is room for improving Eve's understanding. To address this need, her teacher will need to change roles from interviewer to curriculum developer. Better informed, he is now prepared to make choices about the shape and the direction the curriculum should take for students like Eve, which skills are well established, which skills need further support, and which skills are the most sophisticated representations (or abstractions) his students will be able to coordinate.

The interview process began by focusing on how students like Eve build concepts and, while still maintaining that focus, demonstrated its potential to scaffold further inquiry. The same process highlights how students work towards more complex skills within their zone of proximal development (Vygotsky 1978). By using skill theory to operationalize structures of understanding, teachers can evaluate a student's initial understanding as well as how changes in understanding compare with the student's original ideas (Case 1991; Fischer and Bidell 2006). Skill theory provides a tool for analyzing and quantifying degrees of understanding with the student's range of possible understanding. Because skill theory recognizes that changes in context will affect which skill a student will display, the interview process can be seen as a special context in which student and teacher can benefit.

Within this context, the teacher helps the student access work accomplished earlier, ideas already discussed, and/or the relationships explored between ideas and observations. Eve's teacher highlights the problems Eve needs to grapple with in order to build more sophisticated models of how electromagnets work. The world of electromagnetism is represented as a new environment where new and old patterns confront each other. The brain meets the challenge in two ways. In the short term it looks to coordinate older established patterns stored in memory with new experiences in order to make reliable predictions. In the longer term, the brain matures through the investment of energy in building networks and then coordinating those networks in different regions to establish and consolidate new levels and tiers.

The interview was portrayed as an educational tool that supports a teacher's understanding of student views, while providing students the opportunity to recognize and build upon their current structures of understanding. An outcome of the student's effort in challenging his or her ideas is temporary or fragile improvements in understanding that approach his or her optimal level, characterized more objectively through skill theory. Attaining a clearer picture of the variation in structures of understanding that students achieve can help teachers and curriculum designers plan more focused interventions as well as better evaluate the outcome of those interventions.

The goal of interviewing was to create an inviting dialogue where students could experiment with their views, challenge their "actual" structure of understanding and begin exploring structures of understanding that are closer to their optimal level. The goal was not to offer students more complex views that they somehow incorporate into their present world-view. In this environment, the student also has goals to seek a better understanding, and in this interchange with her teacher Eve is motivated to integrate new experiences, coordinate old views with new views, and build more sophisticated structures of understanding. While the conversations do offer scaffolding, they also reveal the student's potential. Curriculum planning beyond the interview would need to address the nature of ongoing support.

With greater insight into the student's world, teachers can better understand how to shape their classroom and lessons so that students can spend more time learning how to recognize and work with more complex patterns that support more powerful predictions about the world. With time and practice students can maintain their ability to perform at their full potential. However with maturity, the bar of potential development is raised, and what is today's potential level is tomorrow's actual level.

Figure 1: Prototype Electromagnet

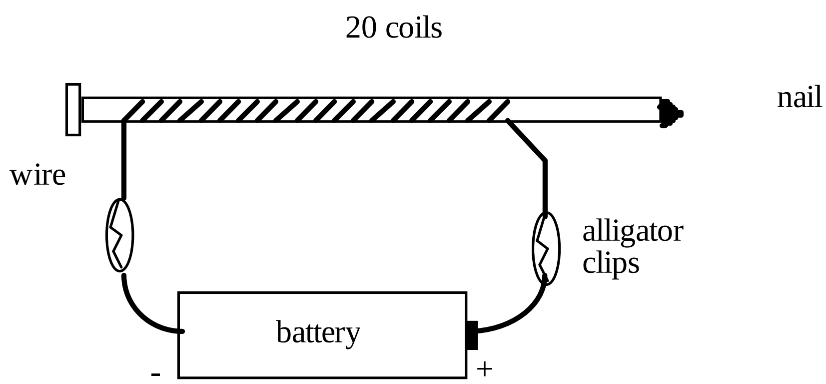
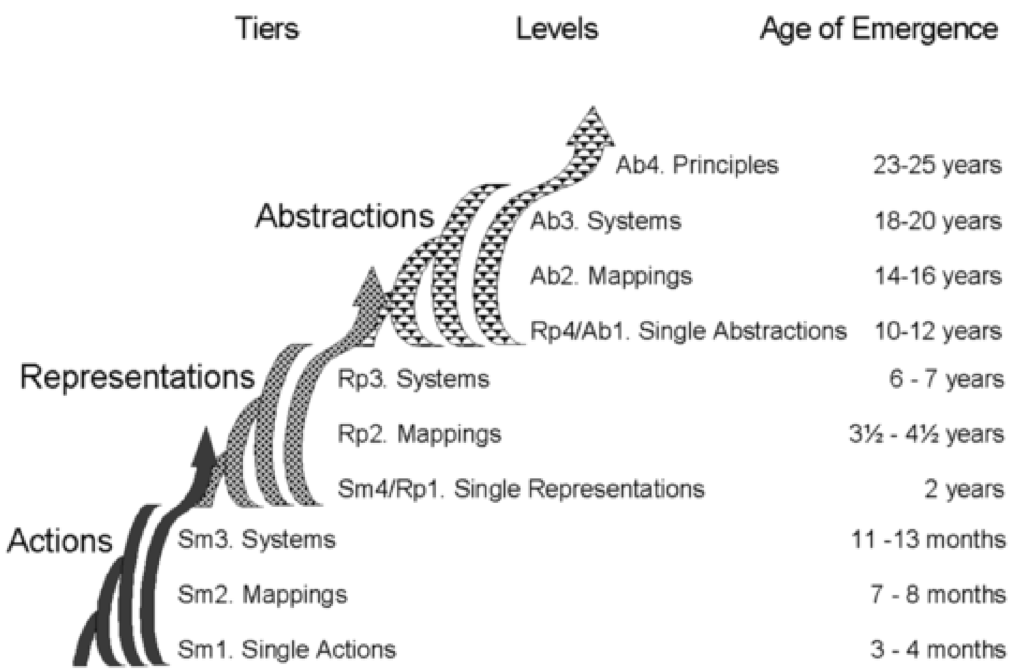


Figure 2: Developmental scale of skill levels

Figure 2. Developmental scale of skill levels & tiers



Schwartz & Fischer

Table 1: Levels of Cognitive Development from Single Representations to Single Abstractions

		TIERS			
Level	Action	Representational	Abstract	Description and Example of Skill	Age of First Emergence
Sm4/ Rp1		Single Representations **[P]** **P =** electromagnet (EM)		Relations of action systems to produce concrete representations of objects, people or events – The name "electromagnet" as the *object* that stands for the "wire-nail-battery ensemble"	18 to 24 mos
Rp2		Representational Mappings **[Q———R]** **Q =** an EM with more wraps **R** = an EM that is more powerful		Simple relations of representations (such as metaphors) – "bigger is better" – The direct relationship between increasing the number of wraps to increasing the strength of the electromagnet	3.5 to 4.5 yrs
Rp3		Representational Systems $\left[\mathbf{Q}\,{}^{a}_{a'} \longleftrightarrow \mathbf{S}\,{}^{b}_{b'}\right]$ *a* & *a'* = variations in wrappings		Complex relations of mappings – Two separate and coordinated relationships such as varying the number of wraps & varying the placement of those wraps along the nail and how these changes independently and in concert change the power of the	6 to 7 yrs

		b & b' = variations on the placement of wraps along the core		electromagnet – Complete circuits is another example[2]	
Rp4/ Ab1		$\left[\begin{matrix} \mathbf{Q}^{a}_{a'} \longleftrightarrow \mathbf{S}^{b}_{b'} \\ \Updownarrow \\ \mathbf{T}^{c}_{c'} \longleftrightarrow \mathbf{U}^{d}_{d'} \end{matrix}\right]$	Single Abstractions $= [\mathbf{Y}]$	Coordination of representational systems to produce abstractions (intangible concepts) – Complete circuits and the flow of electricity through the circuit will create a magnetic "field"	10 to 12 yrs

[2] See Schwartz & Fischer (2004) for a more complete description of how complete circuits illustrate representational systems in student understanding

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