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# Constructive Use of Authoritative Sources in Science Meaning Making

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**Abstract:** The role of authoritative sources of information in a constructivist learning environment has always been ambiguous, especially in science learning where there is a bountiful of knowledge readily available in various sources. Taking a social semiotics perspective in this study, we take the view that authoritative sources are inscriptions of cultural artifacts and science learning involves meaning making of these cultural artifacts. In studying the meaning making process of a group of students doing Problem-based Learning, our findings show that authoritative sources played an important role in deepening and expanding students' scientific knowledge. We also found that constructive use of authoritative sources involves interpretation of meaning in context. Therefore, we conclude that this structural coupling of authoritative sources and context for meaningful sense making has to be taken into consideration in the design of learning environment.

The use of authoritative sources of knowledge, like textbooks, experts and teachers, is often associated with transmission mode of instruction (Scardamalia & Bereiter, 1999). The “knowledge” encoded in books or dispensed by experts are often considered as the ultimate truth to be transmitted to the learners, with due diligence given to the fidelity of transmission so that learners will acquire the valid content rather than develop misconceptions. For this reason, the use of authoritative sources is thought to run contrary to meaning making in a constructivist learning environment, in which students take on an active role in building knowledge through collaborative efforts. The consequence could be a total abstinence from authoritative sources in such a learning environment. This action may, however, deprive the learners of potential resources that could facilitate their construction of understanding. In an attempt to overcome the ambiguous role of authoritative sources in constructivist classrooms, Scardamalia (2002) proposed “constructive use of authoritative sources” as one of the 12 principles for Knowledge Building (p. 77). This principle defines the use of such sources for informing and producing iterative cycles of idea improvement (Zhang, Scardamalia, Lamon, Messina & Reeve, 2007). In other words, it suggests a meaningful deployment of authoritative sources for continual meaning making.

In the context of science learning where there is bountiful of scientific information recorded over the course of history and made readily available in various forms of media, what does it mean to use the authoritative sources constructively? In this study, our goal is to find out the process in which authoritative sources are used constructively in mediating science meaning making. Using a social semiotics perspective of science learning, the study seeks to answer the research question “how do authoritative sources mediate effective science meaning making?” using a social semiotics perspective of science learning.

## Social Semiotics Perspective of Science and Science Learning

From a social semiotics perspective, science is a particular way in which people within a science community make sense of the world with different signs and symbols (Lemke, 1990). From this perspective, science is not so much a set of truth to be discovered. Rather, scientific knowledge is a human construction of a system of meanings (for example, concepts, theories and principles) with various forms of semiotic resources such as language, mathematics, diagrams and techniques. This system of meanings is what we come to know as scientific knowledge (Halliday, 1993).

The construction of scientific knowledge is a meaning making practice that involves the abstraction of worldly phenomena and representation of physical actions, objects and events with signs or symbols. These semiotic resources function as representation of the physical world and form the social tools with which community members could draw upon for meaning making. Members of the science community draw from the system of semiotic resources to construct scientific knowledge. When used repeatedly and regularly, they become recognizable within the community and become the institutionalized ways of talking and writing among the community members. These stable semiotic structures become the scientific knowledge that is deployed within the science community. For example, the Newton's Second Law of Motion states that the acceleration of an object is dependent upon two variables: the net force acting on the object and the mass of the object. Mathematically, it is usually represented by  $F=ma$ . The terms Force, Mass, and Acceleration are abstract representations of physical phenomena that our senses can detect. These scientific concepts are further used to construct scientific laws that depict their relationships which can be represented in mathematical symbols.

Thus, the abstraction of physical phenomena with scientific concepts allows us to build a system of scientific meanings. Therefore, a newcomer into the science community has to appropriate the unique system of social semiotic tools for making meaning *of, for* and *with* them in order to participate meaningfully in the meaning making practices of the community.

## Embodiment of Scientific Meaning in Authoritative Sources

Authoritative sources are credible information repository of scientific knowledge constructed by members of a scientific community over a period of time. They can come in various media (such as books or phonic airwaves) in which scientific meanings are represented with the social semiotic resources, particularly linguistic resources, of the scientific community. Examples of authoritative sources include books, Internet resources, experts and teachers.

In these authoritative sources, products of meaning making practices in the scientific community are made permanent through the inscription of signs and symbols (Stahl, 2006). However, these inscriptions carry no meaning in itself although the scientific community has imbued meaning onto them. Therefore, repeating the particular words verbally or writing them in verbatim does not constitute meaning making. Instead, it is the ability to deploy these systems of meaning strategically so that community members perceive the actions as meaningful that constitute the constructive use of authoritative sources. More specifically, a newcomer into the scientific community is not making any meaning of these symbolic inscriptions found in authoritative sources until they are brought back to life by human interpretation. Thus, students need to learn to interpret meaning embodied in these artifacts. They have to deconstruct the meaning inscribed in these artifacts and reconstruct its meaning in a particular context. It is in this respect that we refer to as constructive use of authoritative sources for science meaning making.

In the following sections, we describe a study which looks at how authoritative sources can be used constructively for science meaning making. We report five instances of this meaningful use of authoritative sources by a group of five students in a Problem-based Learning (PBL) classroom as they went about solving a science problem.

## Method

This study is part of a larger design research that looks at the pedagogical design for supporting students' inquiry learning. The focus of this study is to find out the processes in which authoritative sources are used constructively for science meaning making.

In this study, the meaning making process of a group of five grade 7 students in a PBL classroom was observed. In the PBL activity, students were tasked to find out the cause of a roller coaster accident before any related scientific content knowledge was taught. A scaled-down model of a section of the roller coaster where the accident happened was set up for students to carry out investigations. A computer-supported collaborative learning system, Knowledge Constructor (KC), was used to support the collaboration among the five students during the PBL activity. KC is an online discussion tool that represents discussion threads in a graphical form. A screen shot of KC environment of one of the forum discussions is shown in Figure 1.

The PBL activity was carried out over three 2-hour lessons in a science laboratory. The PBL activity started with the teacher delineating the task to the students. They were to investigate (1) how the ride worked and (2) what might have caused the accident. More specifically, the students had to construct a theory of how the roller coaster cart worked in terms of energy change, and to generate and test their hypothesis of the cause of the accident. A forum was set up in each lesson to support the discussion among students.

The interaction among students was analyzed by threads. Each thread consists of a number of notes that build on to each other linearly (see Figure 1). The analysis of the role of authoritative sources made use of the framework of systemic functional linguistics (Halliday, 1985). More specifically, the ideational metafunction was used to uncover the role of authoritative sources in this science meaning making endeavor. The ideational metafunction refers to the use of linguistic resources for constructing activity, kinds of subject matter and logical relations (Halliday, 1985).

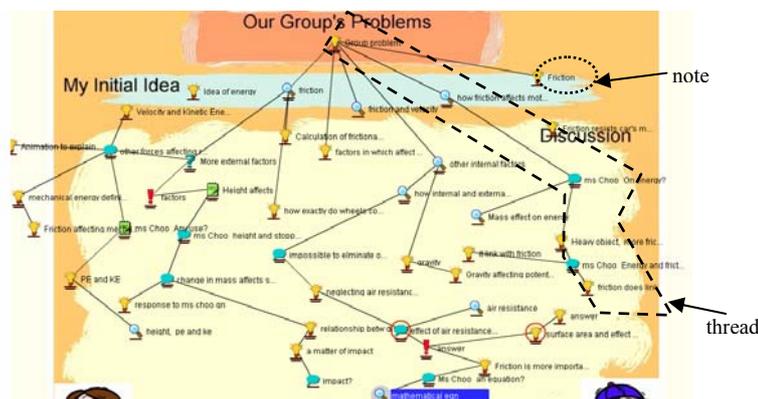


Figure 1. Screenshot of KC environment.

## Findings

The findings show students' scientific understanding progressed from a naïve, everyday worldview of the problem context to a refined conception in terms of the energy changes in the roller coaster system. The presence of authoritative sources in this activity was a strong attribute for the progressive advancement in students' understanding. The sections below describe five instances in which we consider as constructive use of authoritative sources in mediating the science meaning making process in the PBL activity.

### Defining the Scientific Field

Findings from the previous design research cycle showed that students' interpretation of a problem context tended to be based on their own systems of meaning, which may not be consistent with those of the science community. Without any intervention, very little science meaning would be made. Therefore, in this research cycle, the *teacher's voice* was used as a source of authority to direct students' attention to the intended system of meaning. In this case, the teacher's voice was embedded in the instructions in a letter of appointment to the students, as shown in the following excerpt.

#### Excerpt 1

"...This report should include:

1. Explanation of how the ride works in terms of *energy change*.
2. A mathematical expression that summarizes the *energy change* in the motion of the ride from the beginning to the end. ..."

The excerpt shows the teacher defining the system of meanings and semiotic resources in this instruction. For example, the repetition of the noun phrase *energy change* (shown in italics) emphasized the intended subject matter. It thus drew the boundary around which meanings should be constructed. The expanded noun phrases, "explanation of how the ride ..." and "a mathematical expression that summarizes...", further defined the forms of semiotic resources (linguistics and mathematics, in this case) to be used for meaning making.

The result of defining the subject matter and the types of semiotic resources was a barrage of notes posted on KC related to energy change inscribed in both linguistic and mathematical forms. Excerpt 2 shows an example of a thread of notes that resulted.

The notes shown in excerpt 2 contained scientific concepts (e.g., "mechanical energy", "amount of work done by external forces, "kinetic energy (KE)", "potential energy (PE)", "velocity (v)" and "height (h)") and scientific relationships (e.g., " $PE = mgh$ ", "mechanical energy is the energy possessed ... due to its kinetic ... or potential energy ..."), represented in both linguistic and mathematical symbols. These scientific concepts and semiotic structures are collocated with the subject matter *energy change*. They were an indication of the efficient recognition of the relevant systems of scientific semiotic tools, made possible by the purposeful use of the teacher's authority embedded in the instructions.

#### Excerpt 2

Note	Date/Time	Author	Content
14	2006-07-26/ 10:10:06	J	A roller coaster ride uses the work-energy theorem that work done by external forces is able to change the total amount of mechanical energy from an initial value to some final value. The amount of work done by external forces upon the object is equal to the amount of change in the total

			mechanical energy of the object. The theorem is stated in the mathematical equation below. $KE_{\text{initial}} + PE_{\text{initial}} + W_{\text{external}} = KE_{\text{final}} + PE_{\text{final}}$ The left side of the equation includes the total mechanical energy ( $KE_{\text{initial}} + PE_{\text{initial}}$ ) for the initial state of the object plus the work done by external forces ( $W_{\text{external}}$ ) while the right side of the equation includes the total mechanical energy ( $KE_{\text{final}} + PE_{\text{final}}$ ) for the final state of the (object). <a href="http://www.glenbrook.k12.il.us/gbssci/phys/mmedia/energy/ce.htmlobject">http://www.glenbrook.k12.il.us/gbssci/phys/mmedia/energy/ce.htmlobject</a> .
18	2006-07-26/ 10:12:33	M	As the roller coaster train begins its descent from the lift hill, its velocity increases. This causes the train to gain kinetic energy, which is the energy of motion. The faster the train moves, the more kinetic energy the train gains. This is shown by the equation for kinetic energy: $KE = \frac{1}{2} mv^2$
20	2006-07-26/ 10:17:55	J	Mechanical energy is the energy possessed by an object due to its kinetic (energy of motion) or potential energy (stored energy of position). Objects have mechanical energy if they are in motion and/or if they are at some position relative to a zero potential energy position e.g. a brick held at a vertical position above the ground or zero height position
38	2006-07-26/ 10:17:55	D	the PE depends on height and the KE depends on velocity $PE = mgh$ $KE = (1/2) mv^2$

### Expanding Scientific Field

Excerpt 2 showed notes containing scientific knowledge that students had gathered from Internet resources. While such reproduction of texts from Internet resources in verbatim was not considered a meaning making action, they played an important role in expanding students' field of scientific knowledge.

For instance, the initial part of the problem solving process saw students' scientific knowledge confined to a shallow understanding that friction affected motion of an object. They were unable to explain how friction was able to stop a moving object. Neither did they have the necessary language competency to talk about the phenomenon. In excerpt 2, we saw systems of cultural semiotic tools used by the science community for constructing meaning being introduced into the students' sphere of consciousness. For example, the Internet introduced a taxonomy of forms of energy (e.g., mechanical energy, potential energy and kinetic energy) and their association with our worldly phenomenon (e.g., position and motion), represented in culturally-agreed mathematical symbols (e.g., KE, PE, h, v). The Internet resources also introduced the specific structures of scientific meanings built from these concepts. Examples seen in excerpt 2 included identifying relations (e.g., " $KE_{\text{initial}} + PE_{\text{initial}} + W_{\text{external}} = KE_{\text{final}} + PE_{\text{final}}$ ", " $KE = \frac{1}{2} mv^2$ ", "Mechanical energy is the energy possessed by an object due to its kinetic ... or potential energy ..." and " $PE = mgh$ "), attributive relations (e.g., "the PE depends on height and the KE depends on velocity") and causal relations (e.g., "The faster the train moves, the more kinetic energy the train gains." and "Objects have mechanical energy if they are in motion."). Therefore, the presence of the Internet had helped students to be acquainted with the particular language (both linguistics and mathematics) used for talking about the motion of an object in our physical world. In this way, the Internet resources had expanded students' scientific field by creating awareness of the systems of science semiotic tools associated with motion.

However, lifting information from the Internet was not meaning making. This was evident in a mid-activity group report that students submitted to explain the motion of the roller coaster cart. The students merely reproduced what they had gathered from the Internet resources without making connections with the roller coaster phenomenon. For example, in the concluding statements in the report, the students wrote that

"Objects have mechanical energy if they are in motion and/or if they are at some position relative to a zero potential energy position e.g. a brick held at a vertical position above the ground or zero height position.

$$KE_{\text{initial}} + PE_{\text{initial}} + W_{\text{external}} = KE_{\text{final}} + PE_{\text{final}}$$

The left side of the equation includes the total mechanical energy ( $KE_{\text{initial}} + PE_{\text{initial}}$ ) for the initial state of the object plus the work done on the object by external forces ( $W_{\text{external}}$ ) while the right side of the equation includes the total mechanical energy ( $KE_{\text{final}} + PE_{\text{final}}$ ) for the *final state* of the object."

From this conclusion, it was obvious that they had not made any connection between the roller coaster cart and the work energy theorem, " $KE_{\text{initial}} + PE_{\text{initial}} + W_{\text{external}} = KE_{\text{final}} + PE_{\text{final}}$ ".

Although the work-energy theorem and other science semiotic tools gathered may be meaningful to members of the science community, students had not made much sense *of* or *with* them thus far. The next section continues to show how this increased consciousness of the systems of science semiotic tools had made it possible for students to deepen their science meaning making endeavor.

### Deconstructing Scientific Semiotic Tools

Thus far, there were few evidences of students making sense of the scientific knowledge introduced in excerpt 2. However, in the second lesson, we saw the students trying to make sense of the science concepts and relationships when they were prompted by their teacher to explain the roller coaster cart's motion in the given problem. Excerpt 3 shows one instance whereby meaning was made *of* the signs and symbols gathered from the Internet resources.

#### Excerpt 3

Note	Date/Time	Author	Content
4	2006-08-02/ 09:36:23	J	<p><i>the cart starts moving down the slope due to its potential energy it has due to its height at the beginning.</i> There is a relationship between the height of this hill and the speed of the coaster</p> <p><i>the higher the height at the beginning, the more potential energy it has,</i> thus the roller coaster would travel a further distance for a roller coaster on a higher slope.</p>

In excerpt 3, note 4 shows student J deconstructing the term, “potential energy” (found in excerpt 2, notes 20 and 38). The clause, “the cart *starts to move down* due to its *potential energy it has ...*” (excerpt 3, note 4), showed student L identifying “potential energy” as a property that the roller coaster cart “has” which made the physical action of the cart (“starts to moves down”) possible. This implied that student J was making connection between the abstract concept (potential energy) and the physical context (object and action) of the roller coaster.

Deeper meaning of potential energy was evidently made when student J used the adverbial phrase “due to its height at the beginning” to relate the abstract property (potential energy) with the physical position (height) and time (at the beginning) of the roller coaster cart. In this case, a causal relationship was made between them. This causal relationship was further elaborated with the clause “the higher the height ..., the more potential energy it has”. In this clause, student J attributed the magnitude of the abstract property (“more potential energy it has”) to how high (“higher the height”) the roller coaster was. In so doing, meaning inscribed in the mathematical representation, “PE = mgh”, (excerpt 2, note 38) was made.

The above example showed how the systems of science meaning and semiotic resources gathered from the Internet were used to further mediate science meaning making. The deconstruction of the science semiotic tools was not possible without the mediation of the roller coaster context. By relating the symbols to the physical objects and space in the problem context, meaning was made *of* the systems of science semiotic tools. The result was a recontextualization of scientific knowledge found in the Internet resources.

### Reconstructing with Scientific Semiotic Tools

The deconstruction process, as exemplified by excerpt 3, had helped students to make meaning of the abstract concepts associated with energy changes. However, to participate meaningfully in scientific practice, students must also be able to make meaning with the science semiotic tools. Excerpt 4 shows how authoritative sources further contributed to this aspect of students’ meaning making process.

#### Excerpt 4

Note	Date/Time	Author	Content
14	2006-08-02/ 09:49:04	J	$KE_{\text{initial}} + PE_{\text{initial}} + W_{\text{external}} = KE_{\text{final}} + PE_{\text{final}}$ <p>as the cart is coming to a stop, the kinetic energy increases (increase in speed) as the potential energy decreases (due to decrease in height), the KE added to the PE added to the external forces (friction), would equal to the final KE when the cart has stopped, which is 0 and the potential energy, which is also 0, this is because W has used up the energy needed for movement.</p>
			.

			.
23	2006-08-04/ 16:38:13	D	As the $KE_{\text{initial}} + PE_{\text{initial}}$ is always known. In the case of the roller coaster, $PE = mgh$ $KE = (1/2)mv^2$ PE can be calculated from the measurements and KE would be 0. By means of working backwards, we can find the force which occurs in the whole process.  $0 + mgh + [-\text{force} \times \text{displacement} \times \cos(\theta)] = 0 + 0$ $mgh = \text{force} \times \text{displacement} \times \cos(\theta)$

Note 14 shows student J applying the newly made scientific meanings to interpret the work-energy theorem, " $KE_{\text{initial}} + PE_{\text{initial}} + W_{\text{external}} = KE_{\text{final}} + PE_{\text{final}}$ " (excerpt 2, note 14) in the context of the roller coaster phenomenon. In note 23, student D further made use of the mathematical symbols (e.g., "m", "g", "h" and "v") to represent the interpretation, resulting in the derivation of the equation " $mgh = \text{force} \times \text{displacement} \times \cos(\theta)$ ". Hence, this equation, a symbolic representation of the motion of the roller coaster cart, was a reconstruction of meanings using the semiotic tools that the students had made sense of earlier. In this sense, we consider the authoritative sources to have provided the affordances for the continual process of meaning making.

### Questioning Authoritative Sources

The above four instances of constructive use of authoritative sources showed that while students had made meaning *of* and *with* the science semiotic tools, they had not made new meanings *for* these semiotic tools. Meanings for the semiotic tools were often acquired from the Internet resources without questions. For example, students had readily accepted the assumption of negligible air resistance, as given in the Internet resources, for the computation of  $W_{\text{external}}$ . However, we saw them questioning this assumption when a discrepancy between their derived theoretical equation and empirical evidences resulted from their investigation of the cause of the accident. Excerpt 5 shows notes resulting from the investigation.

### Excerpt 5

Note	Date/Time	Author	Content
34	2006-08-16/ 10:09:12	D	...given total weight of the four victims is 340kg: ... $d = 127.78 = 128$ (3sf)
35	2006-08-16/ 10:10:56	D	compared to a car carrying four riders of average 70kg: ... $d \dots = 128$ (3sf) thus, e difference in displacement is: $128 - 128 = 0 \dots$
36	2006-08-16/ 10:50:56	D	Mass (g) 1st try 2nd try 3rd try Average 28      42.0 42.5 44.5 43.0 34      51.0 49.0 48.0 49.3
			.
			.
38	2006-08-16/ 10:58:05	D	mass DOES not affect the stopping distance.. what have we neglected in e process of driving e final equation?

Students had hypothesized that excessive mass was the cause of the accident. During the investigation, they tested their hypothesis using the theoretical expression derived (refer to excerpt 4, note 23) and triangulated the results with the model set-up of the roller coaster ride. Notes 34 and 35 showed the results obtained from the derived expression when different values of mass were substituted into the equation. It showed no difference in stopping distance. Note 36 showed the stopping distances of the cart obtained with the model set-up when different masses were loaded onto the cart. However, it indicated a difference in stopping distances. The discrepancy between the theoretical and empirical results triggered student D to ask "what have we neglected in e process of deriving e final equation?". This prompted the students to look back at their meaning making process, which eventually led to a construction of a new meaning *for* the symbol,  $W_{\text{external}}$ . Finally, the students realized that air resistance had to be taken into account in the amount of external work done by the roller coaster cart ( $W_{\text{external}}$ ), despite what most authoritative sources claimed. In this sense, a new meaning was made *for* the semiotic symbol,  $W_{\text{external}}$ .

This instance thus shows another constructive use of authoritative source. The discrepancy between the physical phenomenon and theory surfaced by the investigation activity triggered the spontaneous reflection on

the students' meaning making process. This led to a further refinement in the students' understanding of the scientific knowledge.

## Discussion and Conclusion

Constructive use of authoritative sources will lead to a continual advancement in students' scientific understanding (Scardamalia & Bereiter, 1999). In this study, we see a refinement in students' scientific understanding as their knowledge shifts from everyday knowledge (everyday ways of thinking and talking about motion of objects) to theoretical knowledge (culturally-agreed knowledge found in the Internet), to deconstructed and reconstructed knowledge (sense making of and with theoretical knowledge) and finally, to reflexive knowledge (meanings made as a result of reflexive thinking of meaning making process). This advancement of scientific knowledge, as reported in the findings, is mediated by the presence of authoritative sources in the learning environment. Figure 2 summarizes this shift in scientific knowledge mediated by authoritative sources.

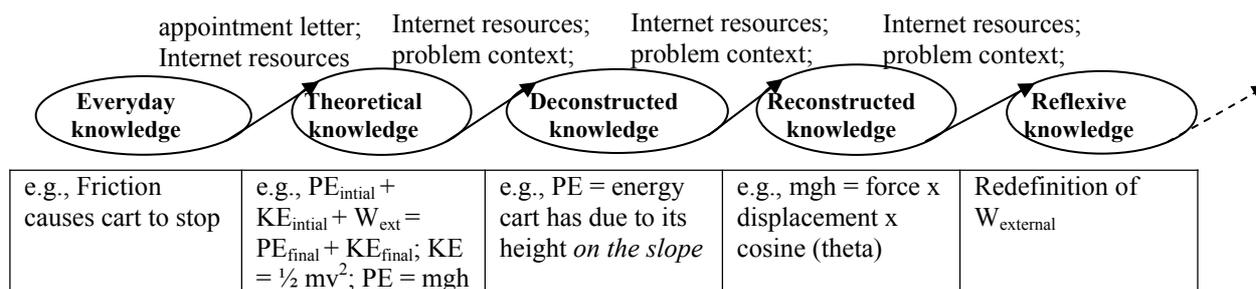


Figure 2. Refinement of scientific knowledge mediated by authoritative sources

From the findings in this study, a few learning points about the constructive use of authoritative sources are drawn. Firstly, it is the role of teacher's authoritative voice. The study shows that there is a place for teacher's authoritative voice in a constructivist classroom (Mortimer & Scott, 2003). However, unlike the traditional didactic teaching approaches, the teacher's voice should not be used for transmitting the decontextualized theoretical knowledge found in textbooks and reference materials. Instead, the teacher could use his/her authoritative status in directing students' attention to the salient features and meaningful patterns of meaning in the problem context which are often missed by novice learners. For example, in this study, the teacher's voice was used purposefully to direct attention to the subject matter *energy change* and to specify the types of semiotic resources that are typically used for science meaning making. The result was an efficient gathering of theoretical knowledge associated with *energy change* inscribed in cultural-specific semiotic tools. Hence, the chances of students' frustration setting in early in the meaning making process could be reduced.

The second implication drawn from this study is the important role of reference resources such as Internet resources, textbooks and encyclopedias in constructivist learning environment. Contrary to its association with acquisition of decontextualized knowledge, the findings in this study show that the systems of scientific meanings and semiotic resources introduced by reference resources such as Internet resources play an important role in mediating science meaning making process. According to Vygotsky (1986), students are often unaware of their own system of meaning derived from their daily experiences with the world around them. This lack of consciousness thus makes it difficult for students to use their own concepts purposefully for meaning making. Instead, the increased awareness of these systems of scientific semiotic tools, made available by authoritative sources, allows students to act consciously with them as the problem demands (Vygotsky, 1986).

However, introducing theoretical knowledge into the sphere of students' consciousness only provides a condition conducive for meaning making. If the process stops at this juncture, the depth of scientific understanding will be compromised. What the students would have acquired from this information gathering exercise will be a set of decontextualized semiotic symbols which are meaningless to them, and hence not transferable. Thus, what is necessary is to orchestrate purposeful meaning making of, with and for these systems of semiotic tools. This brings us to the next learning point drawn from this study.

All meaning is constructed in context (Lemke, 1990). Words and phrases are meaningful only when associated with the physical phenomenon we are familiar with in our everyday life. Our findings show that meaning making happens when the theoretical knowledge gathered by the students from Internet resources is connected to the roller coaster context. This implies the co-constitution of theoretical knowledge and our worldly phenomena. In other words, meaning making cannot happen without one or the other. According to Vygotsky (1986, p. 194), "an everyday concept clears a path for the scientific concept and its downward development ... Scientific concepts, in turn, supply structures for the upward development of the child's

spontaneous and deliberate use”. Just like the case example in this study, students’ naïve understanding of the roller coaster context provided the affordance for meaning to be made of the semiotic tools while the systems of scientific meanings and semiotic resources provided the means for abstraction from the problem context. This dialectical meaning making process simply implies the need to provide both abstract knowledge and a meaningful context for effective science meaning making. In Lemke’s (1990, p. 204) words, “Everything makes sense only against the background of other things like it”. Without a relevant and meaningful context alongside authoritative sources, effective science meaning making is unlikely to happen.

In conclusion, this study uncovers five different ways in which authoritative sources can be used constructively to mediate science meaning making. It also shows that, contrary to popular belief, authoritative sources are necessary for effective science meaning making. However, they cannot function alone. The affordance of authoritative sources has to be coupled with a problem context so that meaning can be made *of*, *for* and *with* social semiotic tools. Therefore, instructional designers have to take into consideration this structural coupling between context and knowledge in their design of constructivist learning environment in order to orchestrate meaningful sense making.

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