<table>
<thead>
<tr>
<th>Title</th>
<th>Making sense of a, b, c’s of science: A dialectics between everyday and scientific conception</th>
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<tr>
<td>Author(s)</td>
<td>Jennifer Yeo, Seng Chee Tan and Kok Sing Tang</td>
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<tr>
<td>Source</td>
<td><em>International Science Education Conference, Singapore, 22-24 November 2006</em></td>
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</tbody>
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Abstract
Problem-based learning (PBL) was first introduced to address the problems of traditional instructional approaches that adopt the “learn first apply later” philosophy (Koschmann, Kelson, Feltovich & Barrows, 1996). But how effective is PBL in helping students to learn science? To this, we adopt Lemke’s social semiotic lens (1990) to investigate the conceptual meaning making process in discourses among students in a PBL context. Meaning, deeply embodied in cultural artifacts, is inseparable from the context, constructed through experiences and interaction, with the knower and known mutually coupled. To learn science is to be enculturated into its unique practices – ways of thinking and communication, and to appropriate its cultural tools constructed to facilitate communication, reasoning and problem solving. We conducted a study with a group of 14 year-old students working on problem related to mechanics over a period of three weeks. Interaction in a computer-supported collaborative learning environment was collected and analyzed. We adopted a micro-genetic approach to understand the meaning making process, with the goal of deriving effective scaffolding strategies. We intend to characterize instances of effective meaning making on scientific concepts and principles in the PBL process, and to derive possible conditions that lead to productive conceptual meaning making.

Keywords meaning making, problem-based learning, social semiotics, everyday concept, scientific concept

Where's the science in the solution?
The following excerpt is taken from a discussion among a group of 4 students in a computer-supported collaborative learning (CSCL) environment in our previous study. The students were discussing how to determine the position to drop food parcel from a moving airplane for victims trapped in a “war zone”.

Excerpt 1

<table>
<thead>
<tr>
<th>Note</th>
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<tbody>
<tr>
<td>1</td>
<td>Tina</td>
<td>Calculate the ratio of the target and distance the parcel is to be dropped. It's a math concept we can fall back on and measurements will be used. It will be accurate and safe method. (jimmy's idea)</td>
</tr>
<tr>
<td>2</td>
<td>Elle</td>
<td>i agree. this method can also be used in real life as we are using ratio</td>
</tr>
<tr>
<td>3</td>
<td>Tina</td>
<td>WE SHALL USE THIS METHOD!</td>
</tr>
<tr>
<td>4</td>
<td>Jim</td>
<td>thanks everyone for ur support…:p sorry</td>
</tr>
<tr>
<td>5</td>
<td>Ella</td>
<td>i agree we shall use this method as it works!</td>
</tr>
<tr>
<td>6</td>
<td>Teacher</td>
<td>What do you mean by &quot;Calculate the ratio of the target and distance the parcel is to be dropped&quot;? …You must be able to explain why the method works other than explaining &quot;it is ratio&quot; method. … is there an equation which shows this? Are you assuming the speed of the car is constant?</td>
</tr>
</tbody>
</table>

Any physics teacher reading note 1 would say that the students’ solution to solve a problem related to projectile motion is not scientific. While students seemed satisfied to have
solved the problem, the teacher’s questions in note 6 (especially the one marked in bold) betrayed her desperation to get students to develop a scientific solution by prompting for “an equation that shows this”.

So what makes a solution scientific or not? It is in the use of linguistic resources which indicates the construction of scientific meaning (Scheppegrell, 2004). From a social semiotic perspective, science is a particular way in which people make sense of the world (Lemke, 1990). It is through the use of particular kinds of language features including specific lexis, grammatical structures and other linguistic resources that the community constructs meaning of the physical world. This constellation of linguistic resources in meaning making creates a unique register characterizing the scientific community – authoritative, objective, abstract and generalizable (Lemke, 1990; Scheppegrell, 2004). The register of scientific discourse forms the social language of science (Mortimer & Scott, 2003).

This social language of science is made up of symbols which function as representation of the physical world. Its meaning is constructed collaboratively through the experiences with the physical world and embodied in the context in which it is constructed. It is through this social language that scientists construct concepts, theories, laws, principles and ways of working with science. They thus form the basic tools with which scientists use to interpret the world. Hence, the social language of science is a product of the scientific community, a distinctive way of talking and thinking about the natural world.

However, the world that students experience in their everyday life is removed from the experiences of the scientific community. The concepts they construct, often described as spontaneous concepts (Vygotsky, 1986), everyday concepts (Mortimer & Scott, 2004) or misconceptions (Vosniadou, 1999), are based on their daily experiences with the world. The concepts are often characterized as informal, spontaneous, empirical and specific, developed without conscious awareness through immersion of everyday social language (Lemke, 1990; Mortimer & Scott, 2003; Vygotsky, 1986). They are in contrast to the theoretical and generalizable scientific concepts which serve to provide causal explanation of the empirical world. One aspect of learning science is to be socialized into the scientific language which provides an alternative perspective for interpreting the world, consistent with the practices of the scientific community. It means to be enculturated into the community’s particular way of thinking, communication and processes. Students learning science has to appropriate the cultural-specific tools to perform effectively in the community.

**Pedagogical approach to science learning**

The knowledge of science is built on symbols. These symbols are abstraction of the physical world, whose meanings are deeply embodied in the context in which they are constructed. When removed from the context, these abstractions carry no meaning. Hence, learning science should involve students making sense of the abstraction (intensional meaning) within the relevant physical context (extensional world). Meaning making of science should thus involve students making connections between the abstract symbols and the concrete objects in the real world. In other words, effective meaning making should involve students being able move up and down the “abstraction ladder” (Hayakawa & Hayakawa, 1990) in order to make sense of the world around them. Hence, context and experiences are important conditions for meaningful science learning.

One pedagogical approach which provides the conditions for science learning is Problem-based Learning (PBL). PBL is a learning approach that was first introduced in the medical school at McMaster University in the late 1960s to address the problems of traditional instructional approaches (Koschmann, Kelson, Feltovich & Barrows, 1996). Although PBL is not originally developed for secondary school science learning, it has since been widely adopted and adapted for use in secondary science education. It focuses exclusively on solving authentic problems, in which the process is shaped and directed
primarily by the student, with the teacher as a metacognitive coach. However, this approach has been criticized to result in shallow knowledge construction (Bereiter, 1992; Bereiter & Scardamalia, 2003) as the knowledge gained tends to be context-specific and not generalizable, as we saw in excerpt 1. Our initial experience with PBL also showed that while students were able to solve the problem successfully, the solution was not based on any theoretical, generalizable solution, as shown in excerpt 1. Hence, such learning may not be transferable.

In this paper, we take on a social semiotic perspective to science learning and seek to characterize instances of meaning making during a PBL activity. We want to find out how students make meaning in the process of learning science through a PBL approach and how the affordances of the learning environment support the meaning making process. We also attempt to draw some conditions that led to the instances of effective meaning making. Such findings will provide information on how we can better support students in meaning making during PBL sessions.

Method

This study takes a case study approach. We looked at how a group of five 14-year-old students went about investigating an accident involving a roller coaster which had overshot the stopping distance after coming down a slope. The topic area related to the problem is the conservation of energy. Students worked on the problem over a period of three weeks in three problem solving stages – understanding the problem situation (how the ride works), hypothesis generation and testing (what causes the accident) and problem solution (recommendations on how to improve the safety of the ride). Mediating the problem solving activity are a CSCL system through which the students discussed their ideas and a scaled model of the ride with which they could test out their hypothesis. During these three weeks, we observed how the group of students went about solving the problem. We analyzed their discussion on CSCL to find out the development of students’ scientific understanding over the three weeks and conditions that make it happen.

In our analysis, we analyzed the register of the CSCL discourse, in particular the kinds of experiential (or ideational) meaning constructed by the students – how language is used to encode experiences of the world. We characterized the meanings as – everyday/scientific, empirical/theoretical and description/explanation/generalization/hypothesis. We then studied how the conditions of the learning environment provided the affordances and support in helping students develop their conceptual understanding.

Findings

The PBL activity was carried out over three weeks, each week with a different focus on the problem. In this section, we describe how the students’ scientific ideas develop over the three weeks which can be characterized into 3 episodes.

Episode 1: Understanding the problem situation (part I)

The teacher Ms Chi had just presented the overarching problem to the students - to find out the cause of the roller coaster accident and to give recommendation on how the safety of the ride can be improved. The problem situation was a familiar situation to the students. Most of them would experience a roller coaster ride before. The first few notes students posted on the CSCL system indicated that students’ prior experience had helped to direct their attention to relevant features of the problem – friction and conversion of energy, as shown in Excerpt 2, which is the first step to meaningful learning.
<table>
<thead>
<tr>
<th>Note</th>
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<th>Idea development</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>D</td>
<td>How does friction affect the point in which the car stops?</td>
<td>context specific; everyday; theoretical</td>
</tr>
<tr>
<td>2</td>
<td>A</td>
<td>There is a change from potential energy to kinetic energy. In the absence of external forces such as air resistance and friction (two of many), the total amount of an object's energy remains constant.</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>A</td>
<td>Friction plays a major role in actual roller coaster physics, where mechanical energy (the sum of potential and kinetic energy) is not constant. The frictional force itself is in direct opposition to the motion of the coaster. The friction of the wheels on the track, the wheel bearings in oil, and wind drag all contribute to the dissipation of mechanical energy throughout the ride, especially at the end of the ride, when the remaining kinetic energy is transferred out of the system by the application of the brakes.</td>
<td></td>
</tr>
</tbody>
</table>
| 7    | D      | In context to my post on "idea of energy", which explains that "In the absence of external forces such as air resistance and friction (two of many), the total amount of an object's energy remains constant.". Isabelle's post is stating that "mechanical energy (the sum of potential and kinetic energy) is not constant... The friction of the wheels on the track, the wheel bearings in oil, and wind drag all contribute to the dissipation of mechanical energy throughout the ride."

What are some factors we can consider? |
| 14   | 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 (KEinitial + PEinitial) for the initial state of the object plus the work done by external forces (Wexternal) while the right side of the equation includes the total mechanical energy (KEfinal + PEfinal) for the final state of the object. [Link](http://www.glenbrook.k12.il.us/gbssci/phys/mmedia/energy/ce.htmlobject). | context general; scientific; theoretical; descriptive generalization |
However, this activity need not be a mindless task, as we shall see in episode 2. For instance, while note 2 and 3 are information from the Internet, it brings to attention the conditions that affect the conversion of energy in a roller coaster system. Note 7 highlights the two ideas and seeks greater understanding of the factors that can affect the roller coaster system, other than friction as originally hypothesized. Following this note is a reformulation of the qualitative description of energy conversion in a form of mathematical equation, a cultural practice of science to represent phenomena in symbolic form, as shown in note 14. This note is instrumental in the progress of the students’ understanding of the problem situation. It provides the students a lens to view the problem situation (this happens only in week 2, episode 2, which we will be discussed later.)

What followed after note 14 was relational meaning made of the different components in the equation, in particular what mechanical energy refers to, what KE and PE are and what they are dependent on. However, this sense-making activity happens at an abstract level as students were making references to generalized context or the roller coaster in general. At the end of this forum, their main take-aways were the theoretical, descriptive generalized model of conversion of energy and its relational meaning of PE and KE. However, they were still not able to relate to $W_{\text{external}}$ which is crucial to understanding how friction affects the stopping distance of the roller coaster cars, a question the students originally started out to answer.

While the learning gain of this forum may be high in abstraction, what the students have gathered here was instrumental in the development of their understanding of the problem situation in the subsequent two lessons. It provides students the framework to understand the problem situation and in the process, to make sense of the abstraction in the equation.

**Episode 2: Understanding how the ride works (part II)**

At the end of the first forum, the teachers were concerned that students had not made much connection between the energy conversion equation and the problem situation. We thus decided not to proceed with the second stage of the activity – hypothesis testing. Instead, we wanted the students to relate the equation to the problem situation. We gave the students three questions (see note 1 in excerpt 3) to prompt them to apply the energy conversion equation as a lens to making sense of the problem situation. These three questions played a central role in helping students make deeper meaning of the abstract representation and making connections to the extensional world.

In excerpt 3, we see student J, in trying to answer the question of how the cart starts to move, applied the theoretical lens of the conversion of energy equation to it, relating the concept of PE and KE in the equation to the temporal/spatial circumstances in the problem context (e.g. “due to its height at the beginning”, “on a higher slope”) as well as logical relations between the physical context and the abstract symbols (e.g. “the higher the height at the beginning, the more potential energy it has”). In doing so, she has moved her understanding down the abstraction ladder in making connections between the symbols in the equation to the specific problem context.

**Excerpt 3**

<table>
<thead>
<tr>
<th>Note</th>
<th>Author</th>
<th>Content</th>
<th>Idea development</th>
</tr>
</thead>
</table>
| 1    | Teacher| 1. Why/How does the cart start to move down the slope?  
2. Why does it come to a stop?  
3. How do we find the stopping distance? | context-specific; empirical; seeking explanation |
| 3    | J      | the cart starts moving down the slope due to its potential energy it has due to its height at the | |

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beginning. There is a relationship between the height of this hill and the speed of the coaster.

the higher the height at the beginning, the more potential energy it has, thus the roller coaster would travel a further distance for a roller coaster on a higher slope.

| 4 | J | \[ KE_{\text{initial}} + PE_{\text{initial}} + W_{\text{external}} = KE_{\text{final}} + PE_{\text{final}} \] |

the kinetic energy the cart has at first is 0 as it is not moving, added to the potential energy it has due to its height above the ground, and added to the external forces before it starts moving (which is 0),

the sum would equal to the final kinetic energy (which would increase as the cart goes down due to motion), and the final potential energy, which would go decrease as the cart goes down due to decrease in height.

The meaning making of the equation is further developed in the later part of the forum when student M posted the formula for calculating friction (note 6):

"as friction exist to oppose motion thus coming to a stop, we need a formula to calculate friction. Once the brakes are applied, the force of friction acts upon the car. The work done by friction on the skidding car is proportional to stopping distance according to the equation

Work = Force * displacement * cosine(Theta)"

and another student X explained how friction brings the roller coaster car to a stop (note 7):

"The cart comes to a stop when energy is also lost by friction which oppose the motion of an object. …Energy is greatly affected by friction that's why the cart stops."

In the above note 6, there is a shift towards an abstract, generalized formula for calculating friction, removed from the problem context. However, note 7 brought the idea down the abstraction ladder by making logical relations between the concept of friction and the problem situation. For example, the clause "as friction exist to oppose motion" in note 6 is used as a cause for "The cart comes to a stop" (see note 7). It further describes the effect of friction on energy conservation, hence relating it back to the energy conservation equation, albeit implicitly.

The above idea development has occurred in different threads in the online discussion. While on its own, they seemed to be insignificant in terms of the learning gains, it is in the rise-above activity that we see the learning gains to be greater than the sum of its individual parts. In excerpt 4, we see student D synthesizing all the bits of ideas that were put forth in different threads of discussion. She then extended it by bringing together the different threads of discussion and relating them to the generalized equation (see note 22 and 23), hence making connections between the abstract equation and the problem context.
<table>
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<th>Content</th>
<th>Idea development</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>D</td>
<td>By law of conservation of energy $KE_{\text{initial}} + PE_{\text{initial}} + W_{\text{external}} = KE_{\text{final}} + PE_{\text{final}}$ $KE_{\text{final}} + PE_{\text{final}} = 0$. Thus, $KE_{\text{initial}} + PE_{\text{initial}}$ must add a negative $W_{\text{external}}$. To calculate $W_{\text{external}}$, we can use the formula: Work = force x displacement x cosine (theta)</td>
<td>context-general; theoretical; description; generalization</td>
</tr>
<tr>
<td>23</td>
<td>D</td>
<td>As the $KE_{\text{initial}} + PE_{\text{initial}}$ is always known. In the case of the roller coaster, $PE = mgh$ $KE = \frac{1}{2} mv^2$ 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. $0 + mgh + [-\text{force x displacement x cosine (theta)}] = 0 + 0$ $mgh = \text{force x displacement x cosine (theta)}$</td>
<td>context-specific; theoretical; explanation</td>
</tr>
<tr>
<td>27</td>
<td>M</td>
<td>actually $W_{\text{ext}} = \text{work done by external forces}$ how do we find that? work done by ext factors = force x displacement x cosine (theta) expand out= (frictional force ) x displacement x cosine (theta) $(FN = - mg ) x \text{displacement x cosine (theta)}$ where: $F_N$ is the normal force in Newton (N), $m$ is the mass in kg, and $g$ is the gravitational force in m/s$^2$. ... Force of friction can be calculated by the formula $F_f = \mu F_N$ $F_f$ is the force of friction in N, $\mu$ is the coefficient of friction, and $F_N$ is the normal force in N.</td>
<td>context-specific; theoretical; description</td>
</tr>
</tbody>
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In this episode, we see the central role played by the problem context in helping students make sense of the symbolic representation of the energy conversion equation. These symbols function as representation of the physical world, a form of abstraction of our experiences, which in itself is removed from the extensional world. It is in the context of the
roller coaster ride that the symbols carry meaning. Hence the three questions asked by the teacher at the beginning of episode 2 were instrumental in prompting students to apply the theoretical equation to the problem situation to make sense of the equation. In doing so, students “move down the abstraction ladder” to know what object or operation each symbol stands for. This helps students in appropriating constructed meanings embodied in context. The context provides the appropriate experience to relate these intensional meaning embodied in the abstractions to the physical world, allowing them to move up and down the abstraction ladder to concretize the symbols encountered and abstract the meaning embedded in these artifacts. The result of this activity is a shift in students’ scientific ideas, from an abstract, descriptive generalization to a more concrete explanation of how the roller coaster ride works.

**Episode 3: Hypothesis testing**

In episode 2, while students were able to relate the abstract components of the equation to the physical world, their understanding of the factors that can affect stopping distance is still based on everyday concepts. From their daily experiences with moving objects, they hypothesize that friction causes a moving object to stop. However, this is only partially true. There are other forms of resistive forces which affect motion besides frictional forces. In this third episode, the students realized that the external work done on moving objects could be caused by other factors such as air resistance, which marks a shift from everyday concepts to scientific concepts.

In this episode, the teacher gave out evidences related to the accident. These include police reports, maintenance reports, and newspaper reports. From these reports, the students’ hypothesis of the cause of the accident was that the total mass of the people in the roller coaster cart had exceeded the maximum mass that the cart would stop before the barrier. They thus set out to test out the hypothesis. They tested out their hypothesis with the physical model of the roller coaster given to them by putting in values into the equation to simulate a hypothetical case. The result showed that there were no differences in the stopping distance from the equation that they had derived on the basis of their understanding of the problem situation. This realization led to student D posting a note on the CSCL:

“mass DOES not affect the stopping distance.. what have we neglected in e process of deriving e final equation?”

Following this, the students realized that friction is only one of the possible forces which result in “energy leaks” from the roller coaster system. They had started exploring the effect of air resistance on the cart’s motion when the discussion had to be terminated due to time constraint – the school term had ended.

This episode involved students working with the given data related to the accident. In manipulating the data, students realized their everyday conception of the situation was not consistent with their experience. Working with real data has helped to shift their concepts from everyday to scientific. It brings to the foreground experiences which often escape our human consciousness.

**Conclusion**

Science is symbolic. It consists of abstraction of the physical world. Meaning is made by relating the intensional meaning with the extensional experiences which involves the interplay between the verbal, symbolic world and non-verbal, physical world.

This paper shows the process in which students make sense of scientific symbols and their physical world. In week 1, we saw students’ everyday concepts of the situation led to the discovery of the energy conversion equation. Mediating the meaning making of the
abstract symbolic equation is the problem context in which students make connection with the physical world. This refines their everyday concepts of the physical world, which in turn helps to concretize the scientific concepts of energy conversion. We see this taking place in week 2. In week 3, we see a refinement of students’ everyday concepts through their investigation of the hypothesis. The realization of other factors other than friction affecting motion further refines their understanding of the world, shifting their everyday conception to a more scientific one. The findings in this study indicate a dialectical process whereby everyday concepts support the refinement of scientific concepts and vice versa. We see that PBL need not result in shallow knowledge construction as claimed. Mediating this process is the learning environment which provides the affordances of authentic context and experiences for students to refine their understanding of the world, as well as teacher’s facilitation in supporting the meaning making process.

In conclusion, this study shows the development of students’ scientific ideas through the PBL process. Meaning making is not a simple linear process of shifting from everyday concepts to scientific concepts, but a dialectical process in which everyday conception interacts with scientific conception and vice versa.

References

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