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How Groups Learn: Implications for Collaborative Work in Science

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Situated in an Asian classroom, this paper took a socio-cultural perspective to group learning by tracing the learning process of a group of students working on a physics problem in a computer-supported collaborative learning environment. Our results showed that the collective knowledge of a group of students progressed from a naïve interpretation of work-energy theorem and the problem context to a more refined understanding of the scientific knowledge associated with the problem context as they solved the problem. Mediating this process of knowledge advancement were social processes such as sharing, negotiation, interpretation, internalization, and reflection. We also attributed this learning progression to the presence and role of physical tools (e.g., Internet resources, teacher, model set-up) and abstract tools (e.g., problem story, experiential activities) in helping students make meaning of the problem context and interpretation of scientific knowledge. The findings highlighted the importance of considering the physical and logical conditions and cultural conventions that might influence the effectiveness of group learning in an Asian context.

Keywords: collaborative learning, problem-based learning, meaning-making

Globalization, knowledge economy, and advances in information technology have been the main driving forces for education reforms introduced in the Asia Pacific region in the past decade (Cheng, 2001). One of the foci in these reforms is the social dimension of learning. In science education, Asian science teachers are responding to these education reforms by adopting contemporary pedagogies such as problem-based learning, project-based learning, and knowledge building that list collaborative learning as one of their key features (see Hong, Wu, Chen, & Li, 2009; So, Seah, & Toh-Heng, 2010). Collaborative learning here refers to the joint effort among students in creating knowledge through interactive social processes rather than individual learning that is merely enhanced by participation in small group work (Stahl, 2006).

However, putting children together on a task need not bring about any meaningful learning. There are social, cognitive and technological factors that can result in dysfunctional groups (Dillenbourg, 1999). In Asian classrooms where deep-seated cultural belief of the social norms in the classroom such as respect for teachers (Richards, 2004) exists, teachers are usually regarded as the sage-on-stage and students as passive recipients of knowledge (Liu & Littlewood, 1997). As a result, Asian science classrooms tend to value individual achievement and teacher-centered approaches (Lee, Chang, & Tsai, 2009). Collaborative learning, which usually requires teachers to act as a facilitator and students as active constructors of knowledge, may present a potential tension. For example, Tan and Tan (2008) found that teachers and students may not know how to assume their new roles as facilitators and co-constructors or be willing to relinquish their traditional roles as authority and recipients in a collaborative setting. This tension may lead to free (un-structured) collaboration or over-scripting of the collaborative actions of students, which
may not result in meaningful learning. Dillenbourg (2002) found that interactions tended to be goal-less in free collaboration while natural processes of collaboration was being interfered in over-scripted collaboration. Cultural tools could also pose possible constraint to group learning. Hubscher-Younger and Narayanan (2003) found that the presence of authoritative sources such as teacher, textbook, or lecture notes could potentially discourage critical analysis in collaborative settings as students tend to align their ideas similar to those they encountered in these sources of knowledge. Yet, the absence of authoritative sources may deprive learners of potential resources that could facilitate construction of scientific understanding (Scardamalia, 2002).

To address the need to support the social and cognitive processes of collaborative learning, technology has been used. Many of these computer-supported collaborative learning (CSCL) systems are designed to provide support for group cognition. Examples include eSTEP (Hmelo-Silver & Derry, 2007) and Knowledge Forum (Scardamalia, 2002). However, technology alone may not be sufficient to bring about collaboration or learning. Studies in CSCL have shown that the quality and quantity of interactions in online environments are lacking. For example, Hewitt and Teplovs (1999) found that discussion threads in asynchronous online platforms tend to be brief. Such findings have been attributed to participants who over-focus on writing new notes instead of building on the older ones (Hewitt, 2005), or not revisiting notes that were read or returning to the discussion forum when they had read most notes (Guzdial & Turns, 2000). Studies also found that activities in online systems did not seem to indicate deep cognitive engagement such as causal explanation (Hakkarainen, Lipponen, & Jarvela, 2002). Arvaja, Hakkinen, Rasaku-Puttonen, and Etelapeltto (2002) attributed such uncritical behavior to the largely symmetrical knowledge that students had. However, they found that even when there was an asymmetry of knowledge, interactions were mostly tutoring in nature rather than knowledge building.

Due to many practical barriers that could make collaborative success difficult to predict, students and teachers may find group learning to be an unproductive nuisance (Stahl, 2006). The problem is exacerbated in examination-oriented Asian schools where individualized achievement, rather than collaborative success, is valued (Lee, Chang, & Tsai, 2009; Richards, 2004). There are also few research studies on collaborative learning of science in the Asian context, (e.g., So et al., 2010; Tao, 2004). Unless we are able to chart the trajectory of collaborative learning and identify ways to support this process, teachers and students will still consider collaborative work inferior to current instructional methods. Hence, the aim of this paper is to illustrate how group learning of science can come about by charting the advancement of group knowledge of five 9th grade students in a Singaporean classroom and to identify the mediating factors that supported its development. The research questions this study seeks to answer are: (1) what is the learning trajectory of a group as they solved a physics problem, and (2) how do social processes and artifacts mediate group learning?

THEORETICAL FRAMEWORK

The notion of group learning draws from two major themes in Vygotsky’s (1978) social theory of development – the role of interaction and the mediation of tools in the process of cognitive development. According to Vygotsky (1978), learning first takes place in an inter-mental plane before moving into an intra-mental plane. On the intermental plane, people help each other to interpret and codify their experiences by using signs and symbols (semiotic resources) to communicate these experiences (Hayakawa & Hayakawa, 1990). Through this process, meanings are also imbued onto the semiotic resources and shared among the group members (Stahl, 2006). In other words, meaning-making is an interactive process (e.g., discussing) whereby ideas are brought together and worked on (Mortimer & Scott, 2003). The meanings constructed and used in joint activity by members of a community is what Stahl (2006) termed as group cognition.

Science, commonly understood to be a body of knowledge consisting of specialized lexical items, generalization, and abstract representation, is testimony of the group cognition that the communities of scientists and science users have constructed to represent the perspective the science community has made of the world (Schleppegell, 2004). A newcomer (e.g., a student) to the science community needs to appropriate the meanings embedded in the system of semiotic resources used by its members and to transform them in the context that is useful for them.
Learning science, therefore, entails making connections between the abstract semiotic system of science and the concrete physical world. From the social theory of cognitive development (Vygotsky, 1978), the act of collaboration among students and teacher in a science classroom not only allows for cultural meanings to be communicated and passed on, but also allows for meanings to be externalized, negotiated, and transformed into new meanings that embody the context in which they are created in before internalizing them for use as their own. Thus, learning science should not be an activity done in isolation, but a collaborative process in which people construct knowledge together.

The second theme in Vygotsky's (1978) theory highlights the mediating role of artifacts in the development of a child's higher mental processes. Artifacts are objects (physical or symbolic) that people create and imbue with meaning for specific uses. In science, the advancement of the atomic model, for example, is mediated by earlier conceptions of an atom (e.g., J.J Thomson's "plum pudding" model and Rutherford's "solar system" model) and advancement of technology which allowed new evidence to be collected about the atom. This scientific advancement is not only collaborative but also mediated by artifacts.

As seen in this example, mediating artifacts could come in the form of physical artifacts (e.g., computers and laboratory apparatus), abstract artifacts (e.g., heuristics, models), cognitive artifacts (e.g., procedures of a learning model), and the presence of other human beings (Kozulin, 2003), thus highlighting the importance of culture-specific tools in shaping how people act and think in an activity. In a collaborative science classroom, we can list laboratory materials, textbooks, teacher, and ideas students put forth as artifacts that mediate meaning-making. However, the presence of artifacts (e.g., technology) in a classroom may not guarantee meaning-making. This is because for a tool to mediate meaning-making, it must satisfy two criteria—the tool must possess properties (affordances) that allow interactions between the user and the tool, and the tool must be perceived as useful and action must be taken by the user (Gibson, 1977).

In short, taking a social-cultural perspective on group cognition focuses our attention on the artifacts that mediate it and the social process of meaning-making rather than on individual’s outcomes. Our emphasis is thus on the scientific meaning made, collaborative discourse practices and mediation of artifacts in the joint production of scientific meaning.

### HOW A GROUP LEARNS: A CASE STUDY

This case study examined how a group of five Grade 9 students from a Singapore high school went about solving a science problem. These five students, four girls and one boy, were in the school's Integrated Program (IP), which was offered to high ability secondary school students. The IP in Singapore allows students to proceed directly to pre-university without taking a national examination at the end of Grade 10. Due to the exemption of this national examination, students in this program were specially selected through qualifying tests and interviews to ensure that they were of high cognitive capability. These students also had high T-score of 250 and above out of 300 for Primary School Leaving Examination (PSLE), a national examination taken by all students in Grade 6. The five students in this study had obtained PSLE T-scores of 250-257.

As part of its response to drive innovation in teaching and learning, the science department of the school designed a science learning approach called THINK cycle, which was modeled after the Problem-based Learning (PBL) approach, an instructional approach that organizes learning around a problem (Savery, 2006). The THINK cycle is a 5-stage instructional model to problem solving, namely trigger (T), harness (H), investigate (I), network (N) and know (K) in each approach, students, working in small groups, are presented with simulated problems of the real world (T). They will identify questions that they need to investigate (H) before embarking on a series of investigation (I), which may include searching for information or conducting experimental investigation. In the process of solving the problem, they will network (N) or collaborate with fellow team members and experts. Finally, they will present their solution to display their knowledge gained (K). In each THINK cycle, each group will be supported by a teacher facilitator who acts as a metacognitive coach.

In this study, the students were doing their fourth THINK cycle for the year, facilitated by Ms Cho, their physics teacher. It was Ms Cho’s second year of implementing THINK cycle. The students were tasked to find out the causes of a fictitious accident involving a roller coaster ride whereby a cart carrying
four riders crashed into a barrier after coming down a slope instead of stopping at the end of the ride. Over a period of three weeks, the students explored learning issues related to the problem context in order to construct a mathematical expression to illustrate how a roller coaster ride would come to a stop at the end of the ride. After the harness stage, they studied evidence collected from a simulated accident scene and hypothesized the cause of the problem. They investigated their hypothesis with a model set-up of the roller coaster and compared the results with evidence derived from the theoretical expression. Students could return to the harness stage if any further puzzling questions arose. Throughout the problem solving process, the students worked in small groups where they were to take up collective responsibility to advance the group’s knowledge as they went through the stages of the THINK cycle. Finally, they wrote a group report to present the group’s solution.

Providing social and cognitive support for collaborative learning was a CSCL system called the Knowledge Constructor (see screen shot in Figure 1). Knowledge Constructor is an asynchronous online discussion tool that represents discussion threads in a graphical form. A screen shot of one of the forum discussion on Knowledge Constructor environment is shown in Figure 1. Each icon shown in Figure 1 represents a note posted on Knowledge Constructor environment (see circled icon labeled “note” in Figure 1). Each different icon indicates the purpose of the note posted by the students, which they could choose from a given list. For example, the circled icon, which represents “My hypothesis”, indicates that the note contains a hypothesis made by the author of the note. The bottom right of Figure 1 shows the legend for the rest of the icons that students could choose from. Each posted note appears on the screen with its title next to its icon. The author’s name and contents of the note are obtainable only when a reader opens the note. The graphical representation of Knowledge Constructor shows links (represented by lines) between notes posted, which displays the interconnectedness of multiple viewpoints posted by students in response to the posted notes. A thread of notes, as shown in Figure 1, is a linear link between notes that build on one another. The platform also provides a permanent record of ideas posted that allows registered users of Knowledge Constructor to retrieve and post ideas anytime and anywhere. A total of three online forums were set up for students’ discussion in this THINK cycle. At the end of each week, students synthesized their ideas and submitted a report to their teacher. A new forum was then set up for students to carry on their problem solving.

The group of five students and their teacher were observed for a period of three weeks as they went about investigating the cause of an accident involving a roller coaster. Online discourse data, captured by Knowledge

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**Figure 1.** Screenshot of Knowledge Constructor environment.
Constructor, formed the principal source of data. In line with social-cultural lens taken in this study, systemic functional linguistics (SFL) was used to study the students' knowledge advancement in Knowledge Constructor. Systemic functional linguistics is an analytical lens that provides a means for describing how and why language varies in relation to its use in different social contexts (Halliday & Hasan, 1985). Focusing on the language-in-activity helps to uncover the context of learning and the meaning construed during interaction.

To understand the trajectory in each thread of science meaning made within the PBL context, we analyzed the kinds of ideas brought forth by the students in the online discourse. We categorized these ideas into domains of knowledge identified by Macken-Horarik (1998) based on the different forms of meaning constructed in different learning situations. Each of these domains of knowledge can be differentiated by distinct language and linguistic features as described in Table 1. In the context of science learning, each domain differs in terms of its degree of technicality, specificity, and concreteness. Each of these dimensions, in turn, can be characterized by specific linguistic features used by the students in their discourse. As the trajectory of meaning-making was traced, social processes and tools that mediated the meaning-making process were identified.

Table 1
Language and Linguistic Features of Different Types of Knowledge

<table>
<thead>
<tr>
<th>Types of knowledge</th>
<th>Language features</th>
<th>Linguistic features</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Everyday knowledge</td>
<td>Narrative; low in technicality; specific and concrete</td>
<td>Clauses with action verbs (e.g., 'run', 'move'), non technical (scientific) terms, specific human and object as participants and events, active voice</td>
<td>Everyday description/explanation of real world phenomena such as &quot;The ball rolled because the boy kicked it.&quot;</td>
</tr>
<tr>
<td>Applied knowledge</td>
<td>Procedural; high in technicality; abstract, specific</td>
<td>Clauses with action verbs, thematic markers of time (e.g., first, second, then), references to tools and materials (e.g., hammer, test-tube), specific participants and events (e.g., displace a pendulum at an angle less than 30°C)</td>
<td>Experimental procedures such as &quot;First, dip equal lengths of a copper rod, a steel rod and a glass rod into molten paraffin wax and withdraw them in order to allow a coating of wax to solidify on them.&quot;</td>
</tr>
<tr>
<td>Theoretical knowledge</td>
<td>Mostly information report and explanation (e.g., causal and relational connections); high in technicality; abstract and general</td>
<td>Technical terms (e.g., acceleration, velocity), generic participants (e.g., it, an object), timeless verbs in simple present tense (e.g., is, has), relational and causal process clauses (e.g., a force is a push or a pull)</td>
<td>Declarative knowledge often found in authoritative sources such as textbooks, internet resources: &quot;Kinetic energy is the energy a body possesses due to its motion.&quot;</td>
</tr>
<tr>
<td>Reflective knowledge</td>
<td>Argumentation (e.g., persuasive and evaluative); high in technicality; abstract and general</td>
<td>Technical terms, generic participants, timeless verbs in simple present tense, logical sequences (e.g., but, because, therefore)</td>
<td>Reflections such as &quot;My theory is that there's a blue moon sometimes because when sunlight hits the earth's atmosphere the blue gets refracted and it hits the moon. But this only happens during the night. We were wrong. The moon looks blue because when there is lots of dust or dirt in the air. ...&quot; (taken from Scardamalia, 2002)</td>
</tr>
</tbody>
</table>
The interpretation of the meaning-making process in the online discourse data was then checked against the teacher’s interpretation of the classroom activity and students’ learning during weekly reflection with the teacher. Students’ artifacts, in the form of draft and final reports, provided another source of data that helped to triangulate our interpretation of the meaning made by the students. In other words, member checks and students’ artifacts made up the various means by which the credibility of our findings was enhanced.

**A trajectory of a group’s knowledge advancement**

The analysis of the interaction data showed the group’s scientific knowledge advancing from an everyday, unstructured theory about an object’s motion to a scientific theory that describes the energy change in a moving object. The advancement of group understanding took place over five key moments as described as follows.

**Explicating prior knowledge.** The PBL activity started with the students engaged in a negotiation over whether resistive forces affected the stopping distance of the roller coaster cart as they attempted to identify the cause of the cart’s failure to come to a stop. Excerpt 1 shows notes with contents taken verbatim from one discussion thread in Knowledge Constructor. Typo errors made by students in the excerpts were not corrected to maintain the authenticity of the notes. Excerpt 1 shows student M (note 21) explaining that “the roller coaster will never stop in the first place since energy is neither gain nor lost” in his counter-claim to an earlier assertion by student J that resistive forces were to be assumed negligible in this problem context. Agreeing that “friction would affect the roller coaster more than the air resistance” (note 30), student J rationalized that “the roller coaster has more contact with the track than the air” and “gravity ... pulling it to the track which makes friction greater” (note 37). Such social discourse, characterized by claim, counter-claim and justification, is described as a negotiation.

The content of this discourse could be described as non-technical, specific, and concrete. Its language features showed that the talk was mostly non-technical

<table>
<thead>
<tr>
<th>Note</th>
<th>Author</th>
<th>Date/Time</th>
<th>Content</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>M</td>
<td>2006-07-26 10:18:45</td>
<td>iff u eliminate other factors like air resistance, friction etc, the roller coaster will never stop in the first place since energy is neither gain nor lost. If, u concentrate on factors like mass, speed the result will be completely different from the one which includes air resistance and friction</td>
<td>Conditional relationship between air resistance and friction with motion of roller coaster, but technical terms like “mass”, “speed” were used in superficial way that did not fully account for the cause of the accident</td>
</tr>
<tr>
<td>30</td>
<td>J</td>
<td>2006-07-26 10:30:13</td>
<td>friction would affect the roller coaster more than the air resistance and cannot be negligible. Friction would cause energy to be converted to heat energy and thus lesser energy would be available for kinetic energy, and distanced object moves is reduced</td>
<td>A challenge to student M’s claim. Technical terms used in explanations were those typically found in textbook.</td>
</tr>
<tr>
<td>34</td>
<td>Ms Cho</td>
<td>2006-07-26 10:35:57</td>
<td>Why do you say that the effect of air resistance is less than friction?</td>
<td>Justification for claim that “air resistance is smaller than friction” is marked with frequent reference to specific and concrete terms like “the roller coaster” or “the track” that were provided in the problem context.</td>
</tr>
<tr>
<td>37</td>
<td>J</td>
<td>2006-07-26 10:39:15</td>
<td>the air resistance is smaller than friction because the roller coaster has more contact with the track than the air. Furthermore, there is gravity acting on the train, pulling it to the track which makes friction greater as gravity has to be overcome to create horizontal motion</td>
<td></td>
</tr>
</tbody>
</table>

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**Excerpt 1**

Note 21: Ms Cho 2006-07-26 10:35:57

Conditional relationship between air resistance and friction with motion of roller coaster, but technical terms like “mass”, “speed” were used in superficial way that did not fully account for the cause of the accident.
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).


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:

\[ KE = \frac{1}{2} mv^2 \]

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.

The PE depends on height and the KE depends on velocity.

\[ PE = mgh \]
\[ KE = \frac{1}{2} mv^2 \]
Sharing theoretical knowledge. Happening in the same online forum were discussion threads that showed information posted by students about the physics behind a roller coaster ride. The information was reproduced from Internet websites in verbatim, as captured by the tracking software installed into the students’ laptop. Excerpt 2 shows one thread that consisted of such information. Here, the information was collocated within the same topic of the work-energy theorem posted in note 14, with subsequent notes elaborating on the different components in the theorem (e.g., KE, PE, mechanical energy). For example, in note 18, “kinetic energy” was described as “the energy of motion” with an equation of “KE = \frac{1}{2}mv^2”, both of which were elaborations of “KE” introduced in work-energy theorem in note 14. Similar elaborations were seen for the other components such as “potential energy” (see note 38) and “W_{external}” (in other threads).

Although the students were seemingly trying to make sense of the work-energy theorem, it was done with equally technical terms such as “mechanical energy”, “work done”, “potential energy”, “KE”, “v”, “m”, with little reference made to the problem context. These technical terms were arranged into some sort of relational patterns to one another such as “KE_{initial} + PE_{initial} + W_{external} = KE_{final} + PE_{final}” in note 14, and “KE = \frac{1}{2}mv^2” in note 18. The absence of any concrete objects/events from the problem context and the presence of timeless verbs (e.g., “is”, “have”) were indications of the generalized and abstract nature of the talk. Such language features have been described by Schleppegrell (2004) and Halliday (1993) as characteristic of scientific knowledge found in authoritative sources such as textbooks. The knowledge construed in this thread was thus considered to be theoretical knowledge.

The result of searching the Internet for information was the uncovering of a body of scientific knowledge related to roller coaster. Although the contents in these notes bore strong characteristics of scientific language, the absence of the specific problem context in the discourse implied that there was no connection made between the material world and the scientific knowledge identified. The abstract concepts in the notes were related to equally abstract concepts and any forms of relationships among them were detached from the problem situation, with little evidence of meaning made of the theoretical knowledge the students had found on the Internet. At the end of the week, the draft report submitted by the students showed little connection made between the theoretical knowledge and their knowledge of the problem context as well. Instead, the report was merely a compilation of large chunks of information found on the Internet. However, this need not be a futile activity. According to Vygotsky (1986), scientific knowledge, which is often brought to students’ consciousness deliberately, provide the structure for everyday knowledge to move up the abstraction ladder. This affordance of scientific knowledge in science meaning-making will be discussed next.

Constructing meaning of law of conservation of energy. To address the lack of connection made between the theoretical knowledge and everyday knowledge in the first online forum exemplified in Excerpts 1 and 2, the teacher, Ms Cho, started a new forum and initiated the discussion with three questions (see note 1, Excerpt 3). Those three questions prompted the students to make interpretation of the work-energy theorem they found on the Internet with things and events of the problem context.

In note 4, student J addressed the question of how the cart started to move. She related the symbols of “PE” and “KE” in the equation to specific space and time in the problem context, thus concretizing the meaning of PE and KE. Furthermore, the causal clause “the higher the height at the beginning, the more potential energy it has” showed student J connecting the concepts of height and potential energy
### Excerpt 3

<table>
<thead>
<tr>
<th>Note</th>
<th>Author</th>
<th>Date/Time</th>
<th>Content</th>
<th>Comment</th>
</tr>
</thead>
</table>
| 1    | Ms Cho | 2006-08-01    | 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? | Questions seeking explanation and process from the teacher to guide the students to apply theoretical knowledge to the problem |
| 4    | J      | 2006-08-02    | the cart starts moving down the slope due to its potential energy it has due to its height at the beginning. There is a relationship between the height of this hill and the speed of the coaster | Causal relationships to connect the cart’s motion to a scientific entity (e.g., “its potential energy”, “speed of the roller coaster”) and its specific space and time in the problem context (e.g., “its height at the beginning”) were indicative of concretization of the meaning of PE. The causal clause “the higher the height at the beginning, the more potential energy it has” showed student J connecting the concepts of height and potential energy as proportional to each other |
| 8    | L      | 2006-08-02    | 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 attributive clause “the kinetic energy the cart has at first is 0” linked the technical term KE to specific state of motion of the object (“not moving”) at a specific time (“at first”) |
| 22   | D      | 2006-08-04    | By law of conservation of energy KE\(_{\text{Initial}}\) + PE\(_{\text{Initial}}\) + W\(_{\text{External}}\) = 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) | A list of logical (identification and consequential) relationships involving both theoretical equations (KE\(_{\text{Initial}}\) + PE\(_{\text{Initial}}\) + W\(_{\text{External}}\) = KE\(_{\text{Final}}\) + PE\(_{\text{Final}}\)) and specific contextualized formulation (KE\(_{\text{Final}}\) + PE\(_{\text{Final}}\) = 0). |
| 23   | D      | 2006-08-05    | 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 + [-force x displacement x cosine (theta)] = 0 + 0  
mgh = force x displacement x cosine (theta) | A specific yet abstract equation, “mgh = force x displacement x cosine (theta)” connects the abstract work-energy equation to the problem context. |
as proportional to each other. This causal relationship, therefore, formed a specific system that connected the abstract term potential energy with the concrete position of the roller coaster cart at a specific time “at the beginning” of the roller coaster ride. A similar concretization and relationship making was also observed in note 8. Such meaning-making patterns of the work-energy equation and the problem context were observed in other discussion threads in the online forum as well. While these notes might seem insignificant by themselves, the outcome was greater than the sum of the individual when synthesized. In notes 22 and 23, the equivalent of the above ideas, together with the formula of Wexternal (discussed in a separate thread), were brought together by student D to generate a mathematical description of the motion of the roller coaster. The result was a specific yet abstract equation that connects the abstract work-energy equation to the problem context. This synthesis could not be possible without the mediation of the abstract and generalized scientific knowledge found on the Internet and the concrete and specific understanding of the problem context existing concurrently in the learning environment. It showed how the concreteness of the problem context had cleared the path for the downward movement of the abstract concepts of work-energy conversion equation and its corresponding components. In turn, the generalized work-energy equation provided the language and system for the students to make sense of the roller coaster phenomenon. This allowed the students to link what they already knew about the problem context to the abstract scientific concepts they had found on the Internet. In doing so, the students moved their “spontaneous concepts towards consciousness and deliberate use” (Vygotsky, 1986, p. 194).

This discourse, marked with linguistic markers of theoretical knowledge and everyday knowledge, as the students make connection between the two ends of abstraction, did not seem to fall into any of the domains of knowledge mentioned in Macken-Horarik’s (1998) types of knowledge framework. To capture this deconstruction and then reconstruction of knowledge as the students made sense of the work-energy theorem in the context of the problem and derived a new expression to represent the phenomenon, we labelled the knowledge construed as contextualized knowledge.

**Applying the law of conservation of energy to the problem context.** Following the derivation of the expression describing the motion of the roller coaster cart, the students went on to hypothesize that the cause of the accident was due to an overloading of the cart. They then tested their hypothesis both empirically and theoretically. Testing their hypothesis theoretically, they input “actual” masses given in “police reports” that were handed out to them into the derived expression (see Excerpt 4). Here, the abstract problem context, in the form of problem story, provided the affordance for carrying out investigation of hypothesis. The use of derived expression in the next phase of an activity represented an internalization of the artifact constructed by the group (Stahl, 2006).

In carrying out the hypothesis testing, student D identified the attributes of the various symbols in the derived equation, thereby making connections between the mathematical symbols with concrete objects and space in the problem context. The listing of mathematical steps accompanied by logical relationships (e.g., “compared to a car ... thus the difference in displacement is ...”) was characteristic of the process of working out a mathematical problem. The advancement of meaning, construed by applying domain knowledge to solve a problem and characterized by using data and listing procedural steps in working out a problem, is referred to as applied knowledge.

**Reflecting on understanding of the law of conservation of energy.** In the previous investigation activity, the students realized that the stopping distance did not change regardless of the mass input into the equation. However, when they tested their hypothesis with the model set up, different masses added onto the “roller coaster cart” resulted in different stopping distances. This discrepancy led student D to post a note on the forum: “mass DOES not affect the stopping distance.. what have we neglected in the process of deriving the final equation?” The discrepancy between empirical evidence and theoretical evidence led them to reflect on their interpretation of work-energy theorem in the context of the problem, triggering an exploration into other factors that might affect stopping distance of a moving object. However, the development in this episode was not fully captured in the CSCL database as the school term had ended before the students solved the problem. Instead, this information was gathered through interviews with the students and from their group report submitted.
Excerpt 4

<table>
<thead>
<tr>
<th>Note</th>
<th>Author</th>
<th>Date/Time</th>
<th>Content</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>33</td>
<td>D</td>
<td>2006-08-16 10:09:12</td>
<td>mgh + umgx d x (-1) = 0</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>finding d, taking U = 0.18</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>given total weight of the four victims is 340kg:</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(340 \times 9.81 \times 23) + [0.18(340)(9.81) x d x (-1)] = 0</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>76714.2 + (-600.372d) = 0</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>d = 127.78</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>= 128 (3sf)</td>
<td></td>
</tr>
</tbody>
</table>

| 34   | D      | 2006-08-16 13:05:15 | compared to a car carrying four riders of average 70kg: |
|      |        |            | (280 \times 9.81 \times 23) + [0.18(280)(9.81) x d x (-1)] = 0 |
|      |        |            | 63176.4 + (-494.424) = 0 |
|      |        |            | d = 127.78 |
|      |        |            | = 128 (3sf) |
|      |        |            | thus, the difference in displacement is: 128 - 128 = 0 |

The group report submitted showed that a new level of understanding was achieved for the symbol $W_{\text{external}}$. In this case, the students realized that air resistance had to be taken into account in computing $W_{\text{external}}$ (compared to their initial understanding shown in notes 30 and 37 in Excerpt 1 where air resistance was considered to be negligible). The written report submitted from the students showed this refined idea when they concluded their report with this comment marked with conditional and causal clauses, “Without adding in air resistance into external forces, the stopping distance is the same, so air resistance does affect the stopping distance, …” and further refined the derived expression to take into account the effect of air resistance. This marked another significant advancement in their scientific conceptions, which resulted from a reflection of their own understanding of the work-energy theorem. Macken-Horarik (1998) characterized knowledge that had resulted from a reflection of personal knowledge as reflexive knowledge. In our context, this reflexive knowledge resulted from an examination into the group’s knowledge instead. Providing the affordance for the construction of reflexive knowledge was the physical model set-up, another form of problem context, which provided concrete evidence that challenged the students’ initial hypothesis.

In summary, the group’s knowledge was seen to advance from a naïve understanding of motion of an object to a sophisticated understanding of the law of conservation of energy and its application to everyday phenomenon. Mediating the process of meaning-making were social processes and artifacts in the learning environment. Figure 2 summarizes the collaborative process of their knowledge advancement and its mediating factors.

DISCUSSION

Premised on Vygotsky’s social theory of development, the case study described above illuminates the trajectory of a collaborative learning process supported by social interactions and cultural tools. The findings show (1) how a group’s knowledge was advanced from naïve ideas to sophisticated
scientific knowledge through collaborative meaning-making, and (2) this advancement of scientific knowledge was mediated by cognitive processes (e.g., negotiation) during social interactions, and artifacts (e.g., problem context and Internet resources) which provide the affordances for relevant meanings to be made.

The first finding, which traces the trajectory of the development of higher order understanding of work-energy theorem, shows that meaning-making must necessarily go through two planes: the social and then the individual plane. In sharing, negotiating, interpreting, applying, and reflecting on the work-energy theorem as the students worked towards solving the problem, the meaning of \( W_{\text{ext}} \) was transformed from a decontextualized definition taken from the Internet (i.e., work done by external forces) to one that was situated in the problem context (i.e., work done by different resistive forces acting on the roller coaster cart). This act of collaboration among students and teacher in a science classroom not only allowed for cultural meanings to be communicated and passed on (e.g., sharing information found on the Internet in Excerpt 2); rather, the act of communication allowed for internalized group meanings to be externalized, negotiated, and transformed into new meanings that embody the context in which they are created in. This externalization, internalization, and then (re)externalization cycle demonstrates that meaning begins as an aspect of an idea in the social platform and is successively transformed into a phenomenon that embodies the social and physical context in which it is made. It is not objectively given and does not exist in a context. In other words, group learning is a necessary process for the development of higher order scientific knowledge and skills. It is not merely a means to foreground students’ ‘disequilibrium’ in knowledge so that a higher ability person can help to close the knowledge gap of the weaker student. Rather, the group setting should allow for symmetry and synchronicity of peers’ cognitive processes, knowledge and action so that they can “do something together” (Dillenbourg, 1999, p. 9). In this case study, the equal opportunity to voice their ideas, or even challenge each other was afforded by the online social platform. The permanence of ideas captured in the CSCL system provided convenient access to the ideas contributed, thus allowing students to extend and elaborate on one another’s ideas, and synthesize ideas contributed in different discussion threads. The result is an advancement of knowledge which is greater than the sum of the individual ideas. The implication
of the first finding is that Asian science teachers transiting from a traditional to a constructivist learning approach should not only provide more opportunities for students to work together but to go beyond using group work as a tutoring strategy for the weaker ones, by considering a more collaborative setting to group work. However, this implication may be a challenge in Asian science classrooms like those in Singapore, known for its strong focus on individual achievement in examination and teacher-centered approaches (Lee, 2008; Lee et al., 2009). This, nonetheless, may be a necessary step in transforming learning that has often been described as “an inch deep, a mile wide” (Bransford, Brown, & Cocking, 2002, p.24) in order to focus on deepening scientific understanding instead.

A shift towards a collaborative learning environment also calls for a re-definition of cultural tools often found in a science classroom. Textbooks, teacher and problems are some common tools found in a traditional science classroom. In this study, similar tools were also listed as key mediating tools for computer-supported collaborative learning (refer to Figure 2), demonstrating that all learning activity is mediated by artifacts (Kozulin, 2003). For example, meaning could be made of the abstract representations of work-energy theorem because of the affordance provided by the objects, spaces, and events of the problem context. In a similar vein, the Internet provided the source for work-energy theorem, a scientifically consistent framework, to be found which acts as a lens for meaning abstracted from the problem context. It was the fit in their affordances that made it possible for students to make connection between the abstract theorem and the physical context, and their meanings were created and transformed as the students acted on them (i.e., derivation of theoretical expression). The problem, both in the concrete and abstract form, was created by the teacher and researchers in this study, which have meanings of work-energy theorem imbued in it. Likewise, the work-energy theorem found on the Internet is a generalized statement that is abstracted from the motion of an object, including a roller coaster ride.

However, the meaningfulness of artifacts must be brought to life by human interpretation, which is influenced by one’s social and historical background. It is exemplified in this case study when critical information found on the Internet about the work-energy theorem and its various components were initially not used to solve the problem until the teacher had directed the students’ attention to the problem context with the three questions found in Excerpt 3, note 1. While there was a fit between the affordances provided by the Internet resources and the problem context, the students had not used them meaningfully in the earlier episodes of the learning activity. This could perhaps be explained by the usual passivity that students schooled in a traditional Asian science classroom have been accustomed to (Liu & Littlewood, 1997). Used to accumulating large amounts of decontextualized knowledge from authoritative sources such as teacher, textbooks and even the Internet, they had thought that their mission was completed when they found the work-energy theorem on the Internet. It was only when they were prompted by the teacher’s questions shown in Excerpt 3, note 1 that they were engaged in making sense of the work-energy theorem. This action helped them realize the affordance provided by the problem context and the generalized work-energy theorem as connections were made between them and new meanings were made for them. In this case, the teacher’s authority had played a key mediating role in supporting the collaborative meaning-making process. We thus see that the authoritative role of the teacher need not be a bad thing although the influence of Western philosophy may seem to give that impression (Lee, 2008). Instead, the teacher in this study showed that teacher’s authority was still needed to facilitate students’ meaning-making by monitoring students’ talk, and posing provocative questions to direct students’ activities, probe understanding, and seek clarification in order to set students thinking more deeply into their thinking, instead of knowledge transmission. Opportunities, however, should be given to students to make mistakes, just like the initial misinterpretation of the work-energy theorem by the students, and to reflect on their (mis)understanding. In other words, there is room for a hierarchical relationship between teacher and students in a collaborative learning environment, albeit it is no longer exclusive to the teacher but shared between the teacher and the students. Such teacher-centeredness in a constructivist learning environment has been termed as “activating teaching” by Bolhuis and Voeten (2001). This is consistent with findings from studies in other Asian science classrooms (e.g. Lee, 2008; Lee, Yin, & Zhang, 2009). Lee et al., (2009), who looked at teacher’s authority in high school classrooms in Hong Kong, showed that teachers were more influential...
on students' self-regulated learning than students themselves. In other words, teacher's authority cannot be undermined even if it seemed contradictory to Western constructivist philosophy. It also implies that besides physical and logical factors, cultural factors should also be considered in designing for collaborative learning. Roles for traditional tools such as the authoritative status of a teacher may still be necessary in helping students self-regulate and direct their learning process. Similarly, tools such as the Internet should not be used for accumulation of information but as a source for communicating the scientific semiotic resources to the students. Problems, instead of being devoid of reality in end-of-chapter questions and traditionally used to provide students with practice for examination, should be crafted with the complexity and messiness of real life situations.

CONCLUSION

In conclusion, this paper describes a case study to illustrate the trajectory of development of scientific knowledge of a collaborative group in an Asian classroom. We showed that collaborative learning, mediated by familiar classroom tools, can result in the advancement of scientific knowledge in a computer-supported environment. However, traditional classroom tools mediating the learning process may need to be redefined. Authoritative sources, such as the Internet or even textbooks, could be used constructively to solve problems rather than as sources of facts to be transmitted to students. Problem should be complex, resembling those in the real world so that new meanings could be made for new information encountered. Teachers can use their institutional power constructively to facilitate students' engagement in the problem-solving and learning process by asking questions, paying attention to students' responses, stimulating student interaction and providing direction on collaborative tasks while allowing students to decide on the content they learn and when to learn. The findings in this study will, hopefully, provide some direction to Asian science teachers making the transition from a traditional teacher-centered science classroom to a constructivist student-centered one.

REFERENCES


