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A Learning Journey in Problem-based Learning in a Physics Classroom

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Most educational theorists now promote *activity in context* and *authentic activities* to engender more meaningful forms of learning. Problem-based learning (PBL) is one of such pedagogy whereby students work in groups to solve "real world" problems. However, when these practices from the real world are introduced into classrooms, school teachers could encounter many challenges, such as curricula and individual constraints. In this ethnographic study, we describe what happened when a high school physics teacher adopted PBL in his classroom in an attempt to move toward inquiry-based instruction. Using cultural-historical activity theory, we compared his instructional activities with a referent PBL model derived from literature, so as to surface the tensions and contradictions in the activity system as he introduced new practices into his classroom. We found that the challenges he faced arose from disparities between the motives driving everyday practices and schooling, which we attribute to differences between academics and the lived-realities of practitioners. We suggest that researchers work collaboratively with teachers towards an equilibrium point. This joint reflective practice could potentially enable authentic pedagogy such as PBL to be implemented meaningfully and realistically in an Asian society that has long placed a premium on academic achievement.

Keyword: problem-based learning, curriculum reform, activity theory

Traditional school learning has been criticized to bring about inert knowledge because it is divorced from the context in which knowledge is meaningfully used (Brown, Collins & Duguid, 1989). Coupled with the demands of a knowledge-based economy and advances in technology, schools are changing their curricula towards a more progressive form of education to develop meaningful knowledge and skills needed in the 21st century. In Singapore, the Ministry of Education (MOE) has urged schools to embrace more innovative inquiry-based pedagogies for science learning (Lui, 2006). In response, one local high school, T Academy (pseudonym), designed and introduced a problem-centric framework based on a Problem-based Learning (PBL) approach, following similar implementation in Singapore tertiary institutions.

Problem-based learning is an instructional approach that makes use of an authentic problem as a meaningful task to situate learning. It involves students conducting research, integrating theory and practice, and applying knowledge and skills to develop a viable solution to a defined problem (Hmelo, 2004; Savery, 2006). PBL originated from a Canadian medical school to help medical students apply the knowledge they had learnt when faced with real medical cases; it was later adopted in school science classrooms to overcome the criticism for the exclusion of real world and meaningful context in traditional science learning (Kolodner et al., 2003). Modeled after real-world problem-solving, PBL differs from school-based problem-solving in several ways. First, in PBL, students work on complex, ill-defined, open-ended problems that mirror those in the real world. Textbook problems, on the other hand, have been described to be well-defined with few variables to consider and pre-determined set of solution(s). Second, there is no one right way of solving a problem in PBL, compared with school science problem-solving that often involves standard rule-based procedures. Students doing PBL work collaboratively to transform, solve, resolve problems or even abandon lines of solution in favor of other options in the light of challenges

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and new information found. Third, compared to the role and authoritative image of teachers portrayed in a traditional science classroom, the teacher acts as a metacognitive coach in a PBL classroom. As a metacognitive coach, the teacher would model questions that students should be asking, motivate them to reason when faced with novel problems, prepare them for transfer of strategies and knowledge, give them timely feedback, and gradually reduce the scaffolds when the students become more competent. Such a role contrasts with the traditional role of teachers that coaches students through a fixed solution path for well-defined problems.

However, historical data seem to bear evidence that classroom practices are resilient to changes (e.g., Fullan, 2008). These data tend to highlight teacher factors – their pedagogical understanding, beliefs and attitudes –amidst systemic constraints such as learning environment, assessment and organization of learning as challenges to curriculum reform. Teachers implementing curriculum reform are often caught in a tangle of contradictions when new practices are introduced into their classrooms. By contradictions, we refer to the historically accumulated dynamic tensions between opposing forces in an activity system (e.g., schooling). With most PBL studies conducted in tertiary institutions and mixed results obtained from the few conducted in high schools (e.g., Liu, Hsieh, Cho, & Schallert, 2006), the implementation of PBL in T Academy could potentially face challenges due to contradictions within the activity system. We hypothesized that understanding these contradictions at the societal level will allow more informed interventions to be introduced into the classroom to ensure greater chances of succeeding in curriculum reforms and ultimately student learning. This entails understanding teachers' actions when implementing new practices in their classrooms. Therefore, this study aims to uncover the interrelationship between the social and societal processes that could affect a teacher's actions in implementing PBL. The over-arching research question for this study is: "How was PBL enacted in a secondary school science classroom, and why?"

RESEARCH METHODOLOGY

This study was the first phase of a design research (Design-based Research Collective [DRC], 2003) that aims to understand the implementation of PBL in T Academy so that its theory and process can be refined. Design research is a methodology for the study of learning in context through systematic design and study of instructional strategies and tools (DRC, 2003). With the conduct of design research typically carried out in the actual setting where learning takes place, the findings we report here are closely bound to the context of study. Thus, we do not claim generalizability of our findings; instead the findings reported in this paper could potentially serve as a useful case example for researchers faced with similar situations. Rather than aiming for generalizability, we hope to achieve "transferability" (Lincoln & Guba, 1985) by providing adequate information for the readers to decide whether the findings are applicable to their own situations. To help us understand the contradictions and tensions underlying the implementation of PBL in the science classroom, cultural-historical activity theory (CHAT) is used as an analytical lens in this study to understand the contradictions and tensions underlying the implementation of PBL in the science classroom.

CHAT as a theoretical lens to understanding enacted PBL

School learning is a specific historical activity, with specific goals that drive classroom practice (Miettinen, 1999). To make sense of what is taking place among people and objects, CHAT provides a holistic theoretical lens for understanding learning that is taking place in a classroom. Based on Soviet psychology, specifically that from Lev Vygotsky, it explains the development of human learning in which the individual and social are interlinked (Wertsch, 1981). While the genesis of the model can be traced to the three-level scheme (activity, action and operation) that structures an activity into a chain of actions targeted at short term goals and specific acts afforded by the environment, it is Engeström's (1987) expanded version that is currently adopted (see Figure 1). By considering an activity to be object-oriented and a cultural formation with its own structure, it can be used as an organizing principle for explaining human behavior. It takes into account the cultural and historical aspects of the *activity*, such as the community members (*community*), *rules* by which the activity is taking place and *division of labor* among members of the community, besides the focus of the activity (*object*) and the instruments (*tools*) that are used by the participants (*subject*) to accomplish the object.

By taking activity as its unit of analysis, CHAT allows actions taken to be understood not only at the social level but also at the societal level. CHAT provides a critical lens to analyze how societal structures have influenced certain actions and how they impair others, as well as how these social structures are internalized by subjects and embodied in their behavior just as agents reinforce or change structures. These contradictions and tensions open up possibilities to intervention so that changes to those structures that have become problematic in curricula reforms can be made (Roth & Lee, 2007). By empirically examining contradictions in situations that might escape the consciousness of participating individuals, CHAT analysis could offer participating individuals concrete solutions in workplaces or classrooms, which is the focus of our study.

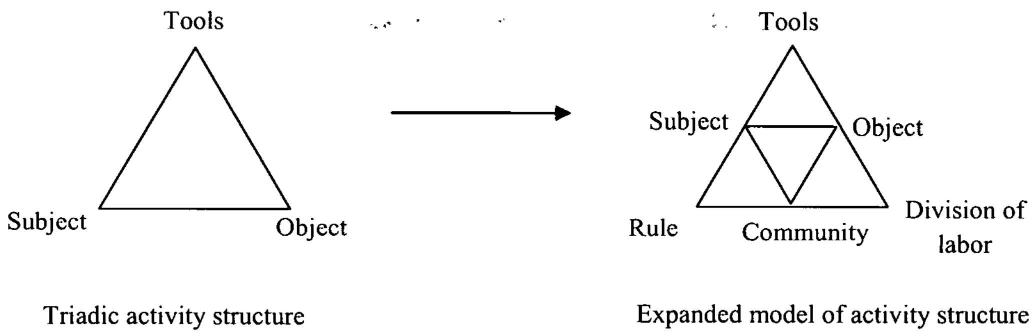

Figure 1. Engeström's (1987) expanded activity structure.

METHOD

Research site

The study was conducted in a Singapore public high school that offered a new program to high-ability students who could proceed directly to pre-university levels without taking a national examination after completing Grade 10. To engage students in learning science through authentic problem-solving, the school developed a PBL framework, known as the THINK Cycle. It is a five-stage collaborative learning process centered on problems, comprising (T) rigger, (H)arness, (I)nvestigate, (N)etworking and (K)now. In this approach, students, working in small groups, are presented with simulated problems of the real world (T). They then 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) with fellow team members and experts and finally present their solution to a panel of judges (teachers) to demonstrate their knowledge gained (K).

In this study, we examined the implementation of one THINK Cycle by a physics teacher in a class of 23 Grade 9 students. We focused on Mr Chen (pseudonym), a physics teacher, and four students among 23 high-ability and mixed-gender students. Mr Chen, who was also heading the school's technology department, had taught in the school for five years. He was one of the pioneering teachers involved in designing the THINK Cycle framework. As an anchor in the physics program, he designed all the physics problems. When this study was conducted, it was the first year Mr Chen implemented the new curriculum and the third THINK cycle he had conducted with this Grade 9 class.

The students, comprising three girls (SX, M and Sya) and a boy (E), of age 14 years old, were selected because they were Singaporeans and had studied in the local schools. These criteria were crucial because any tensions caused by different educational and language background were outside the scope of this study. The students participated in a two-week PBL lesson unit, consisting of six sessions, which required them to solve a problem involving a road accident between two vehicles. The lesson unit was carried out over 5 lessons (a total of 7.5 hours). A presentation session was conducted three weeks after the last lesson of the THINK Cycle.

Data sources

A number of data sources were collected to understand how PBL was enacted by Mr Chen in the high school science classroom. Interaction data formed the main source of data for the reconstruction of the enactment of THINK Cycle. As the mode of interaction among the participants was mostly done face-to-face, a video camera was used to capture their interaction. The video camera, fitted with an external zoom microphone, was also used to capture the class interaction when the focus of the group's activity was centred on the teacher's interaction with the whole class. In such situations, the video camera was placed next to the group of students observed so that the students' talk could still be captured if it took place in the middle of the teacher's instruction. However, there were occasions when the students were not seated together during class interaction. In those occasions, the video camera was placed at a corner of the classroom that was the least obtrusive to the students. To ensure that teacher's and students' talk was captured in good sound quality, an additional audio recorder was carried by the teacher and another placed on the students' table. Students and the teacher were quickly acclimatized to the presence of video cameras and audio recorders as this was not their first experience with the first author, who was the sole person collecting data, in their classroom. The video and audio data collected were then transcribed and analyzed.

Interviews were also conducted with Mr Chen to understand the intentions behind some of the teacher's actions. Questions include those seeking understanding of his intended objectives for the enacted THINK cycle, perception of the degree of achievement, as well as those related to his observed pedagogical strategies. Interviews with the students sought to find out their perception of their own understanding and objectives behind their actions. The interviews also served as a members' check of the researchers' interpretation of the video data.

Data analysis method

The analysis of the data involved two key areas – reconstructing the THINK cycle activity and understanding the rationale for the enacted activity. Video data and interview data formed the sources for the analysis of these two areas. Analysis of video data took place in two stages: (1) organization of classroom discourse at each stage of the THINK cycle, and (2) reconstruction of the THINK cycle activity using CHAT. The interview data provided explanation of the actions perceived in the THINK cycle.

In the reconstruction of the THINK cycle using CHAT, learning episodes from the video data were firstly identified by their orientation to particular goals to THINK cycle. Meaningful parts of the discourse that were directed at the achievement of goals were transcribed with greater emphasis on capturing the content and function words uttered but less emphasis on stress and intonation of the utterances. The transcription followed the conventions of conversation analysis suggested by Ten Have (1999). Specific conventions used in this paper are provided immediately after Excerpt 1. Side-talk or off-task talk, such as discussions on other subjects' homework, was not transcribed. From the transcripts, the components of the activity system were identified by discourse features described in Table 1. These features are based on systemic functional linguistics (Halliday & Hassan, 1985), a framework for relating language with context. From the perspective of systemic functional linguistics, an activity is enacted through language and thus, the study of the language use in activity offers a means for describing how and why language varies in relation to groups of users and to usage in social context. Thus when applied to a social context such as a classroom learning, it informs what is talked about (field), the relationship between the speaker/hearer or writer/reader (tenor) and the role of language (mode) in the discourse. It highlights the functional purposes foregrounded by speakers/writers in response to the demands of various

Table 1

Mapping Field, Tenor and Mode with Components of the Activity System

Dimensions	Language features	Components of activity structure
Field	• Type of activity: commonsense or specialized Refers to the type of activity going on [commonsense, everyday, specialized, problem solving]	Object
	• Subject matter: Refers to the general and specific topics the text is about.	
	• Type of subject matter: Refers to the type of subject matter [everyday, specialized]	
Tenor	• Relationship: Refers to the relationship between the speaker/writer to his/her audience [power, status and expertise]	Rules, division of labor (roles), community
	• Degree of contact: Refers to the physical and verbal proximity between speaker/writer and receiver [distant/intimate; frequent/infrequent]	
	• Type of involvement/emotions: Refers to the type of involvement or emotions that the speaker/writer expresses towards others or the subject matter	
Mode	• Role of language: Refers to the use of language as constitutive/ancillary to action, interactive/non-interactive	Tools
	• Channel: Refers to the channel in which the text is delivered [graphic or phonic]	
	• Coherence: Refers to the coherence of the text [coherent or not coherent]	

tasks and the cultural practices of the community. It is in this respect that discourse analysis is used for identifying the components of the enacted classroom activity system. CHAT is then used as an organizing framework to represent the factors mediating the THINK cycle activity.

Another source of data that provided insights into the enactment of the THINK Cycle was the interviews. While the video data informed how the PBL activity was enacted, the interview data extended this understanding by providing evidence from the participants on why certain actions were taken during the enactment of PBL. Analysis of interview data was by means of content analysis based on teachers' response to the interview questions.

WHAT HAPPENED IN MR CHEN'S CLASSROOM

What we observed was an almost linear enactment of the THINK Cycle according to the stages of (1) trigger, (2) harness, (3) investigate, (4) network, and (5) know, which we described in the following sections using Engeström's expanded activity system to organize the findings.

Trigger

The THINK Cycle started with Mr Chen presenting the trigger problem to the class. The trigger problem, named after the popular American TV series CSI, focused on the concept of projectile motion. It involved a collision between a car and a lorry, the impact of which flung one of the back passengers in the lorry out of the vehicle. The students' task was to find out which driver was at fault in this accident and to provide evidence to support their claim. In presenting the trigger problem, Mr Chen made clear his expectations to the students. They were to prepare prosecution information, forensic evidence to re-create the scene, and to include "the physics principles and the math principles" because "we will test you whether you are really good in physics". While the students played the roles of forensic investigators, Mr Chen demarcated his role in this problem-solving task as he told the students, "(I am) your big big boss. You are supposed to report to me". At the end of the session, Mr Chen told the students to work in groups to discuss who they thought was responsible for the accident and why. Each group was to send their hypotheses to him before the next lesson.

Harness

In the second lesson, Mr Chen held a whole-class discussion on the hypotheses submitted by each group of students. As he went through each group's hypothesis, he was quick to dismiss ideas that were tangential to the scientific content of projectile motion (for example, not wearing a seat belt) but focused on taking up useful scientific ideas and expanded on them as he went along (see Excerpt 1).

Excerpt 1 shows how Mr Chen persisted in engaging students in expanding their ideas on "impact", "distance" and "speed" until "the three equations of ... kinematics" were brought up by student S in turn 190. Praising the student S for the "good question", he turned the focus of the talk to an invitation to students to ask questions and to suggest topics they wanted him to teach. Mr Chen continued to give preferences to topics and questions related to scientific concepts of motion as he dismissed questions on the evenness of road and distance of collision. Later in the conversation, he picked up questions on "angle which the guy flew" and promptly promised to give the class a lecture on projectile motion. He also agreed to give a lecture on friction at the request of some students.

Investigate

There were two main events – lectures and problem-solving sessions – taking place in the investigation stage over the four lessons. The lecture session took place immediately after the whole-class discussion of hypotheses. Mr Chen started with a short lecture of 10 minutes on friction, in which he concluded that the concept was "of no use" to the trigger problem. This was followed by a lecture on projectile motion (see Excerpt 2) in which he introduced scientific terminologies used in projectile motion (turn 257), described the characteristics of projectile motion (turn 257), discussed the conventions of using symbols as representation for projectile motion (e.g., turn 280), and stated formulas (e.g., 282) as well as equations related to projectile motion (e.g., turn 320). As he taught, he made frequent checks on students' understanding (turns 280 and 288). At crucial teaching points, he emphasized that "at this stage is very important who cannot see this" (turn 280), and checked if students had "any problems" (turn 320).

Thereafter, Mr Chen and the students were engaged in a series of problem-solving activities when he demonstrated how different problems on projectile motion could be solved, provided practice questions for students to work on, and directed them to solve one part of the trigger problem in a similar manner as the practice questions. Another area of investigation was to find out the traffic rules and penalty code for offences before deciding on the charges to impose on the offender. Here, the students carried out the search for information from the Internet on their own as instructed by Mr Chen.

Network

Networking was not exactly one stage on its own but it happened continuously with the other stages. Here, it refers to communication between students and teacher and among students in the group. Mr Chen took a more authoritative role as he closely guided the students to identify the learning issues during the harness stage, taught the concepts of projectile motion, and closely guided them to use standard procedures during the investigation stage. Through questioning, prompting and evaluating, Mr Chen ensured that he maintained control over the direction of talk.

Excerpt 1: Moving very fast

Turn	Speaker	Content
145	Mr Chen	... Both are wrong. Why? (.) ...
146	S3	The impact of the pickup on the car::
147	Mr Chen	Uhuh?
148	S3	Shows that it's kind of great.
149	S4	For the body to have flown so far, it means that the Hilux is moving very fast.
150	Mr Chen	So you think the Hilux is moving very fast? So how do you prove that the Hilux is moving very fast?
151	S4	Because the body moves so far.
152	Mr Chen	So you are going to use the distance flung by the victim. What principle are you going to use?
153	S3	Inertia.
154	Mr Chen	Inertia. So you are going to use inertia to calculate the speed of the Hilux.
		.
		.
		.
172	Mr Chen	...Group five. You have not told me how are you going to use inertia to prove the speed. You must really prove the speed.
173	S1	Can we use the tyre marks to prove the speed or something?
174	Mr Chen	How are you going to use the tyre marks to prove the speed?
175	S2	We believe right, that the BMW right, broke down after ( ) because you see right, he tried stopping before the traffic lights. The tyre marks stuck there. But then he had to skid all the way until the traffic light. The Hilux is right behind the BMW. The Hilux is in a way pushing the BMW. That means they are both travelling at a high speed.
176	Mr Chen	Yes. Uhuh? Ya. But what my question is how are you going to calculate the speed here ...
		.
		.
		.
190	S	Can we use the three equations of ... kinematics, ...
191	Mr Chen	Good question. Class ...

Transcription conventions:
:: indicates prolongation of the immediately prior sound.
(.) indicates a tiny "gap" within or between utterances.
( ) indicates transcriber's inability to hear what was said.
(( )) contain transcriber's descriptions rather than, or in addition to, transcriptions.
- indicates a cut-off

The only time Mr Chen took a more facilitative role was during the investigation of traffic rules and penalty code.

The students worked with one another only when they were solving questions related to the trigger problem. When they were not, they would be seated apart doing individual seatwork. When they got together, they would help one another with the practice questions, with the more capable students mentoring the weaker ones. When they worked on the trigger problems, the talk tended to be more collaborative but only the more capable ones were involved.

Know

At the end of the THINK Cycle, each group presented their solution to a panel of teachers, including Mr Chen. Taking the role of examiners, the teachers quizzed the students on their knowledge of projectile motion and the

Excerpt 2: Lecture on projectile motion

Turn	Speaker	Content
257	Mr Chen	...Now a projectile motion like this right? You have to consider the horizontal components and the vertical components. So now I'm going to put here horizontal which is called your X direction (.) and vertical (.) which I called this the Y direction. (.)In this particular case do you think it is horizontal projection? (...) ... The good news for you class is that horizontal component and vertical component don't affect each other.
		. . .
278	Mr Chen	... But now I just want to find my magnitude the distance ((referring to horizontal distance)).
279	S	S cosine titre.
280	Mr Chen	Again? S cosine titre. Ya. Well done! Ok who cannot see this? (.) S cosine titre. Who cannot see this? Up your hand please. At this stage is very important who cannot see this? (.) Cannot see? Ok. (.) Can anyone tell me what is cosine theta? Adjacent. Let me say this ((horizontal distance)) pretend this is my SX this ((vertical distance)) is my SY. Adjacent is?
281	Students	SX.
282	Mr Chen	SX correct? Hypotenuse is? S right? So SX equals to S cosine titre. SX equals to S cosine titre. Can see?
		. . .
288	Mr Chen	U sine titre. Ok. Who cannot get this part here? Who cannot get this part here? ...
		. . .
318	Mr Chen	... My maximum height this is S equals to zero ok? My maximum height is somewhere around here. My final velocity in the Y direction is zero. (.) Then I want to find the time taken to the maximum height.
319	S	UV equals to U plus AT.
320	Mr Chen	UV equals to U plus AT. Any problems? ...

procedure they followed to solve the trigger problem, with each student in the group taking turns to answer questions. They were then awarded marks based on their abilities to answer those questions.

THE ENACTED ACTIVITY SYSTEM OF MR CHEN'S THINK CYCLE

The enactment of THINK Cycle can be summed up using Engeström's (1987) activity system as the organizing structure. Here, we consider the teacher and his students as the subject of this activity.

Mr Chen and his students were observed to be spending most of the THINK Cycle sessions doing problem-solving. The interview revealed that the main purpose was to achieve the learning objectives stipulated in the GCE 'A' level syllabus. Mr Chen declared his main objective was "to get the kinematics projectile motion taught to them." Likewise, the students ranked content mastery as their top priority in this THINK Cycle. Evidence suggests that mastery of content knowledge related to projectile motion was the *object* of the activity.

With regard to the role of the problems, Mr Chen explained that "I give them a problem so that by getting them to tackle the problem, the SIOs will have been covered ..." *SIOs* refer to the specific instructional objectives specified in the GCE 'A' level examination syllabus, which was to describe and explain non-linear motion. Elaborating further, he explained how the different practice problems were carefully chosen to achieve the SIOs. For example, the first practice problem was to ensure that students were "accustomed to resolving vectors, x component and y component, to solve problems" and the second question was "to get them to see that all they had to do is to look at the displacement rather than distance" as he referred to the meaning of the symbols in the equation. Thus, it seemed that Mr Chen used the problems as his *tool* to help students master the content knowledge.

The emphasis on SIOs also suggests that a larger community, which was not physically present in the classroom, was influential on the actions of Mr Chen and the students. This *community* includes the curriculum planners and the examination board. As mentioned by Mr Chen during the interview, his main objective was "to get the kinematics projectile motion taught to them". Other objectives, such as "the understanding of the (Singapore's) laws ... which is not deemed essential to the topic but something good to have" were not given attention. In this case, the science curriculum (rule) guided his practices in the classroom. Similarly, the examination board had profound influence on Mr Chen's action in class. For instance, the mechanics of problem solving was directed at the rubrics of assessment. The video data showed Mr Chen instructing students what they should or should not do when solving problems. When asked to comment on these remarks during the interview, Mr Chen said that "ultimately the examination is 40 %. ... in the marking scheme, we don't have a scale to grade their understanding of concepts but we mark them based on the steps they give". Therefore, he felt that "the assessment objectives are very important" and that "PBL is not very strong in getting them (students) into structures" in terms of procedural steps. As a result, he had to "hammer them with the necessary structures because even in A levels, there is a certain right way of doing things". The examination criteria set by the examination board were perceived as important rules to which both the teacher and students had to comply with when mastering the content knowledge. Thus, larger policy planners played a key authoritative, albeit invisible, role in this THINK activity.

The *outcome* of the THINK activity was probably best summed up by student SX as she could "only use it for the question. But I don't think I can use it for other questions." This view was shared by student M who found it difficult to transfer her knowledge to new situations. It seems that while the students were taught about the characteristics of projectile motion and procedural knowledge on solving problems related to projectile motion, and although they were able to answer questions during the *Know* stage, students perceived their content mastery to be confined to the specific problems they had encountered.

In summary, the enacted THINK activity can be represented in Engeström's expanded activity system model as shown in Figure 2.

COMPARISON BETWEEN ENACTED THINK CYCLE AND PBL

For the purpose of comparison, we used widely-cited descriptions of PBL activity offered by Savery (2006) and Savery and Duffy (2001) as references. We will refer to them as the referent PBL. The enacted THINK Cycle does not resemble the problem-solving activity of the referent PBL. The actions *in the enacted THINK cycle* seemed to be motivated by the accumulation of large bodies of knowledge whereas the referent PBL focuses on developing students' ability to solve authentic real-life problems. The apparent difference between the motivations of the two activities could explain the differences in the mediation of the two activity systems.

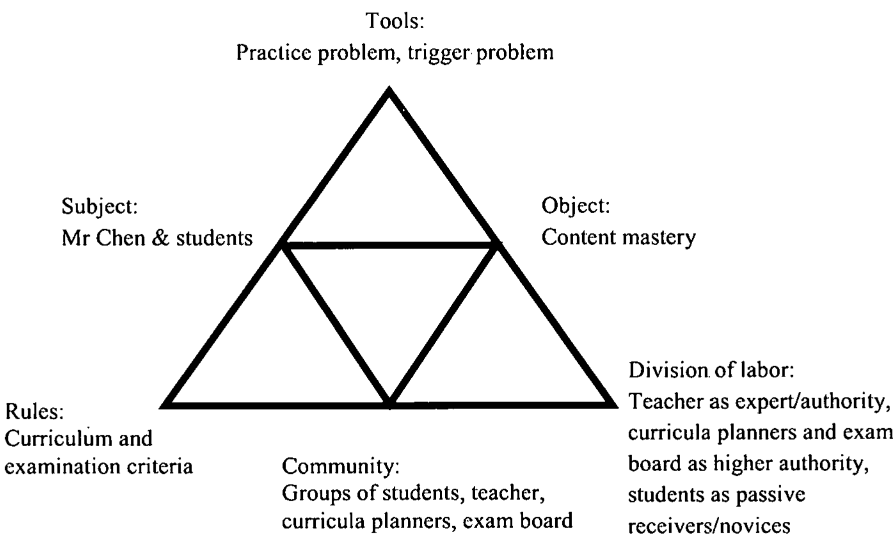

Figure 2. Activity system of the enacted THINK Cycle.

The first difference between the referent PBL activity and the enacted THINK Cycle is the role of problems. Problems have strong presence in both THINK Cycle and PBL approach. However, the presence of problems in the learning environment does not predispose the activity as participation in authentic activity. Instead, it is the mediating role of the problems in the activity system that determines an activity's biasness towards any of the learning theories. For this THINK Cycle, the evidence suggests that problems (practice and trigger) are means for students to apply and to transfer the knowledge presented during the lecture to a different context. In contrast, problem is the center of learning events in the referent PBL.

Another difference between the enacted THINK Cycle and the referent PBL lies in the nature of the problems. In the referent PBL, problems are ill-structured and authentic. For instance, in medical schools, the problems are taken from medical files, thereby assuring the authenticity of the problems. In contrast, the problem in the THINK Cycle was well-structured and devoid of the nuances of everyday problems. Although the trigger problem may seem more ill- structured compared to the practice problems given by Mr Chen, it was artificial. The complexity of the problem was artificially constructed by the teacher and dependent on the meaning that the teacher embedded into the problem context. Furthermore, the close guidance provided by the teacher in solving the trigger problem reduced its complexity to simpler forms. Therefore, as observed, throughout the process the students only needed to identify the values of the parameters in the equation—pattern recognition. Opportunities to develop other problem solving skills were absent from this activity.

Another main difference between the THINK Cycle and PBL approach is the role of disciplinary content knowledge. PBL approach was conceived to ensure the practicality of content in medical profession (Savery, 2006). It therefore perceives content knowledge as a tool for mediating problem solving. However, in this THINK Cycle, content learning was the object of activity, as observed in the episodes and also mentioned by the teacher and students during the interviews.

The roles played by the participants in the classroom are also different in this THINK Cycle and PBL. In the referent PBL, collaboration among students is emphasized and teacher plays the role of a metacognitive coach (Savery, 2006). However, the teacher was the authority and expert in the classroom in this THINK Cycle. The students, on the other hand, played the complementary role of passive learners. Among themselves, they worked with one another collaboratively though there seemed to be more engagement among the capable ones.

Finally, the enacted THINK Cycle and the referent PBL differ from each other in the cultural norms that influence their behavior. The behaviors of the teacher and students in this THINK Cycle were largely influenced by the perceived fixed structure and organization of curriculum needs. On the contrary, the referent PBL is modeled after the collaborative and fluid nature of problem-solving found in the real world (Savery & Duffy, 2001).

In short, the activity structure of the enacted THINK Cycle is fundamentally different from PBL in terms of the object, tool, roles and rules, as summarized in Table 2. However, while the comparison was meant to uncover some fundamental differences, it is not our intention to regard the referent PBL activity as the "correct" or "superior" form of activity. It merely provides a means for the comparison between PBL and THINK Cycle.

CONTRADICTIONS AND TENSIONS BETWEEN THE TWO ACTIVITY SYSTEMS

The comparison between the enacted and the referent PBL shows the fundamental differences between the components of the activity systems. Although a popular and contemporary approach to learning was adopted by the teacher and the students, there seemingly was

Table 2
Comparison of Activity Systems

	The referent PBL activity system	The enacted THINK Cycle classroom
Subject	A group of students	A group of 5 students and teacher
Object → outcome	Object: problem Outcome: solution	Object: content mastery Outcome: content knowledge (procedural knowledge)
Tools	Content knowledge	Problems
Rules	Real world problem solving	lecture, drill-and-practice, curriculum and examination expectation
Community	Groups of students in the class, teacher	Groups of students, teacher, school curricula planners, examination board
Division of labor	Students as problem solvers, teacher as metacognitive coach	Teacher as authority and expert, students as passive receivers/novices, curriculum planners and exam board as higher authority

no breakthrough in the kinds of learning activities and behaviors with the transition to modernity. The enacted THINK Cycle remained predominantly the activity of *schooling*. The reasons for what had taken place could be explained by contradictions and tensions that exist when practices of the real world, which PBL is modeled after, are brought into the science classroom.

Engeström (1987) described school to be an institution that is historically removed from societal activities. Its activity, in particular that in Asia classrooms, has been described to have a structured and fixed curriculum organized in some discrete manner, fixed and routinized problem solving method, lecture, drill-and-practice and rote-learning, with an aim to do well in examination (Mok & Morris, 2001). This contrasts with everyday activities that involve problem-solving with unclear solutions, disciplines or procedures. Fundamentally, the motive of personal growth and fulfilment that drives everyday activities is different from the motive of succeeding in examination that drives schooling. Although the teacher and the students may have the intention to embrace PBL, the motive to succeed in examinations supersedes the need to seek far transfer for real life applications. The gulf between the motives of the two activity systems created a tension in the classroom when aspects of real life problem solving were introduced. According to Leont'ev (1978), all actions are in relation to the motive of the activity. In everyday problem-solving, one would depend on what one knows to solve a problem; while in school, problems are used to help students master content knowledge. This "strange reversal of object and instrument" (Engeström, 1987, p. 74) results in a tension when PBL was introduced into the science classroom. In trying to address this contradiction, Mr Chen made use of problems to teach both content knowledge and procedural knowledge in the THINK Cycle when the subject matter was related to syllabus related contents. Describing the "'A' level (as a) peculiar content knowledge", Mr Chen explained his actions by justifying that "in A levels, there is a certain right way in doing things ... if you don't show the steps, no matter how good you are and how much you understand ... the problem or the concepts, you will not do as well as someone who don't know as much but know the structures well." To address this contradiction between object and tools, Mr Chen resorted to the use of practice problems to drill the students into the rudiments of examination questions while trying to remain authentic to PBL.

The contradictions and tensions within and between the components of the activity system could perhaps be understood by the tension between exchange and use values ascribed to the motives of each activity – everyday and schooling. In schools, content mastery is considered essential for getting good examination results, which in turn determines a child's academic path (Lave & Wenger, 1991). Problem solving skills and metacognition are useful and are essential skills in dealing with everyday problems but may not be so crucial in getting by high-stakes examinations that test mainly recall and procedural knowledge. The introduction of aspects of real-life problem solving into the central activity of school resulted in a tension between what is useful and what is exchangeable. As Mr Chen puts it, "PBL will be able to role model better the skills that are required for working life ... (but) PBL approach is not strong in getting them into structures ... (which) are there in the 'A' level curriculum". Mr Chen was merely "trying to find a system to get the best of both worlds" when the components of another culture was introduced into the dominant form of activity in the classroom.

IMPLICATIONS

The introduction of authenticity into teaching and learning into Mr Chen's classroom was to reflect the changes towards new educational aims, to enhance educational reality, and to reform educational practices. Despite the fundamental changes to the examination structure in this school, we found that there was little effect in the enactment of the new pedagogy compared to the traditional. This finding was similar to those found in many Asian classrooms that introduced innovative practices (e.g., Lee, 2008), which suggests that for successful school reform, structural change and introduction of new pedagogies are necessary starting points, but may not be sufficient conditions for effective change.

In Singapore, the local Ministry intended to provide students with rich and deep learning experience to prepare them for a knowledge-based society, as evidenced in the new program created for students with good academic records by exempting these students from a national examination at Grade 10. This was a bold move considering the high premium that has been placed on these examinations by students and their parents. The school had also devoted time and effort to identify new pedagogies and developed their own framework for problem-based learning. These are structural changes which are conducive for teachers to experiment with new pedagogies. However, the structural changes need to be coupled with changes in epistemological beliefs and practices (Hung, Ng, Koh, & Lim, 2009).

This study reveals the invisible relationship between the social and societal levels of a school activity system. Mr Chen's actions were influenced by cultural and historical factors of schooling with which he was familiar. Reproduction of knowledge endorsed by authorities and success in examinations are so deeply entrenched in the teacher and students, which supersedes the more pragmatic use of knowledge. Thus, Mr Chen saw PBL as an existing challenge in an education system that is constrained by a state-mandated curriculum and an expectation to primarily produce good examination results. Rather than being unsympathetic to Mr Chen (and educators in similar situation) and dismissing it as a "lethal mutation" (Collins, Joseph & Bielaczyc, 2004) of the referent PBL, we view Mr Chen's effort as an attempt to find spaces in-between the conventional teaching methods and the innovation. While the outcome may not directly address the aims of curriculum reform, Mr Chen's effort is a crucial starting point. To address this "lethal mutation" of PBL, the community (teachers, students, policy makers, researchers) needs to collaboratively address the contradictions and tensions in the school activity system. As researchers, we could seek the new within the old but not regard the contradiction negatively; rather they could be perceived as the impetus for change, innovation and expansive learning. They present the preconditions and initial forms of a new type of learning that must be developed within the basic activity of society (Lee & Roth, 2008). What is exhibited as PBL on the ground entails on-going, contextual interpretations and negotiations of meaning within the community. It is crucial for the researchers and practitioners to work collaboratively to find a balance between theory and practice as well as between the ideal and do-able.

CONCLUSION

How do we bring about school reform through introducing new pedagogies in classrooms? Our learning journey in PBL in a science classroom showed that beyond structural and curricular reform, the answer lies in the enacted practices in classrooms. Using CHAT, we uncovered contradictions in the classroom activity systems, which can provide impetus for change, innovation and transformatory learning. From the perspective of a team of researchers, the contradictions between the referent and enacted PBL activity could perhaps be an indication of the tensions between the researchers and practitioners' perspective of PBL in Singapore – a traditionally yet academically high-achieving Asian society.

Our next step in this design research is perhaps more treacherous because, rather than imposing or training the teachers from the point of aloof evaluators, we suggest engaging teachers as co-researchers using a design experiment approach (DRC, 2003). By so doing, we could shift our attention from proving the effectiveness of a pedagogy to improving a pedagogy. It requires a fundamental change in the perception of the relationship between researchers and teachers, from that of an expert-practitioner relationship to that of co-designers of classroom environments. It leverages distributed expertise among teachers and researchers towards the common goal of improving classroom practitioners, rather than imposing additional burden to either party to assume unnecessary and unrealistic roles. In addition to improving classroom practices, it brings in learning as well as instructional theories in the design process, and provides opportunities to test the viability of these theories. Through this process, researchers and teachers could externalize their beliefs, negotiate differences in perspectives, and collaboratively improve the enacted practices in classrooms through several iterations. This partnership between the academics and practitioners, we believe, will bring about deep changes while harnessing the wisdom from both learning theories and everyday practices.

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