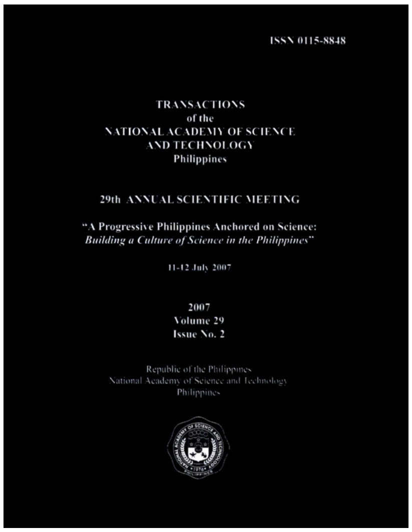
TRANSACTIONSNASTPHL

https://transactions.nast.ph

ISSN 0115-8848 (print)
ISSN 2815-2042 (online)

Vol. 29 Issue No. 2 (2007)
doi.org/10.57043/transnastphl.2007.4462

Transactions NAST PHL, is the official journal of the National Academy of Science and Technology Philippines. It has traditionally published papers presented during the Academy's Annual Scientific Meeting since 1979 to promote science-based policy discussions of and recommendations on timely and relevant national issues as part of its functions as a national science academy. Starting in 2021, this journal has been open to contributions from the global scientific community in all fields of science and technology.



Problems and Possibilities at the Heart of Science Education

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Citation
Lee YJ. 2007. Problems and possibilities at the heart of science education. Transactions NAST PHL 29(2): 212-225. doi.org/10.57043/transnastphl.2007.4462

Trans. Natl. Acad. Sci. & Tech. Philippines 29: 212-225 (2007)
ISSN 0115-8848

Problems and Possibilities at the Heart of Science Education

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Widespread science education is a necessary though not sufficient enabler for national development. Nation states increasingly recognize that the foundation for such highly desirable knowledge is first laid in schools and therefore, the provision of quality science education is critical. In order to improve science education, what we need is not more science but better science, what we really need is not so much knowing what to teach but knowing how to teach, and how to teach it well. Inquiry-based science amply fulfils all these stringent criteria for it is at the heart of science instruction. However, implementation always poses many challenges, which I will illustrate with some case studies from Singapore. Three ideas are proposed that might facilitate successful implementation of inquiry science in schools (a) continue teaching science as inquiry and believe that it works, (b) search for indigenous solutions and success stories, and (c) fully support the efforts of local teachers.

Science Education and National Development

Let me first begin by parking out the importance of science education and its relation to national needs to briefly set the context.

It is widely acknowledged that one explanation behind the large disparities between north-south countries is the level of national involvement in science and technology. Those countries which were lucky enough to be caught up in the first Industrial Revolution or its recent equivalents have seemed to maintain a robust technological, and hence, economic edge. Economic prosperity in these nations seems to function in a virtuous cycle with both political stability and advanced technological innovation.

It is no wonder that a recent Asian Development Bank (ADB) article asserted that

> **A concerted effort to improve education, science and technology, and innovation capacity is needed. It requires education specifically for the knowledge economy, for research and development, to foster development and innovation in science and technology, and for policy reforms. (ADB Review 2006, p. 6)**

All nation states increasingly recognize that the foundation for such highly desirable knowledge is first laid in schools and therefore, the provision of quality science education is critical. A good grounding in science among young people will allow countries to participate in the knowledge-driven economy. We need to remember too that science education is a necessary though not sufficient factor for economic development (Caillods et al, 1997; Shofer et al, 2000). I think this is one thing we all can safely agree on.

It is therefore rather perplexing to see call after call for reforms in science education. Everywhere we turn, there seems to be some sort of crisis in education. This situation has apparently gotten out of hand in the United States where it has been said that the field of "science education… has been plowed and replowed, but the topography remains much the same from decade to decade" (Ponder and Kelly, 1997, p. 244). James Rutherford, former Chief Education Officer of the American Association for the Advancement of Science, put it this way,

> **In the half-century after World War II, we did some good work in science education, but the lasting results were meager. Science curricula, science teaching materials, science teaching, science teacher education, science education research remained much as they were before the war. (Rutherford, 2005, p. 385)**

What Rutherford and other historians have found is that so-called reforms in education are problematic, there are persistent problems in how we teach science that refuse to go away. Understandably, this state of affairs is troubling both to policymakers and practitioners alike, which has thus led to recent efforts by the international science education community to search for evidence-based practices—"what works"—that lend themselves to concrete change on the ground (Lee et al, 2006).

Given the theme of this meeting, "A Progressive Philippines Anchored on Science: Building a Culture of Science in the Philippines," I want to make a somewhat controversial statement now. We already know that reform in (science) education is hard. Changing a culture is truly a Herculean task. In order to improve science education and by extension assist national development, what we really need is not more science but better science, what we really need is not so much knowing what to teach but knowing how to teach, and how to teach it well (Yager and Lutz, 1994). As Reinders Duit (2007, p. 10) summarized the trends in the literature, he said that the "major emphases are now on improving practice, i.e. on the development of powerful teaching and learning environments and teacher professional development."

What Is Inquiry and Why It Matters

By now, it is obvious that good teaching practices, especially those associated with inquiry-based learning (IBL), are at the very heart of a good foundation in science. Over the last five decades, IBL has been recognized as an essential component of a sound education in science (Bybee et al, 2006). Inquiry-based instruction is a very broad umbrella term and would include related practices such as the investigative approach, hands-on science, laboratory work, the scientific method, problem-based learning to name but a few (Grandy and Duschl, 2007). Inquiry-based learning is, however, not easy nor comfortable for teachers and students who are exposed to it for the first time. For most people, their initial reaction would be something like what the philosopher Nietzsche once said, "If you desire peace of soul and happiness, then believe; if you would be a disciple of truth, then inquire."

I think Nietzsche has hit upon an important fact here; many want peace of soul and happiness, which person enjoys hard work, sweat, puzzlement, and mental disequilibrium? Nonetheless, we neglect the explicit teaching of inquiry, and the using of inquiry to learn science at our own peril. Remove inquiry and we are left with a very impoverished and emaciated form of science; remove inquiry and students are incapable of asking the most basic questions concerning the universe.

Implementation of Inquiry-based Learning Is Difficult

We seem to know what inquiry is, how it works, why it is so successful, why it is something as incredible as holidays, apple-pie, and mothers. But, and this is a very big but, inquiry science is also notoriously difficult to implement effectively. Inquiry science is not easy and poses many challenges for classroom teachers all over the world. Inquiry science as how I understand it, is really at the heart of science education, full of possibilities for real change and improvement but it is also something that presents us with much grief at the same time (Anderson, 2007).

It is said that a chain is as strong as its weakest link. The chain for inquiry science as an effective teaching strategy is strong, the chain for evidence that inquiry-based learning boosts students' interest in science strong, and the chain for coherent curricular frameworks that are based on inquiry are plentiful. What persistently has been found to be wanting and identified to be the weakest link in the whole chain is the actual implementation of inquiry science by the teacher, either through lack of resources, time, or inadequate training or discomfort with inquiry and other reasons. These obstacles are sometimes imagined, and oftentimes real.

For the curriculum leaders and educators here in our audience, you would agree with me that successful implementation is always contingent upon numerous (unforeseen) factors that revolve around people, policy, and place, the three deadly "P"s (Cohen, 1990; Honig, 2006; Keys and Kennedy, 1999). Teachers can be told what to do, teachers can be shown what to do, and they even can speak about what they will do but ultimately whether people are doing inquiry science in the classroom remains an empirical matter. And because inquiry is such a weasel word that refuses to conform to one simple definition, there are as many interpretations of what is inquiry as there are teachers. And thus we can be lulled into believing that I'm teaching in a constructivistic manner when in actual fact the dominant pedagogy in my classroom is very didactic.

Inquiry Science Implementation in Singapore

This very danger has in fact happened occasionally in Singapore. Because change is always hard, educational reforms including those in science education have experienced uneven adoption and successes after a decade of Thinking Schools, Learning Nation (TSLN) reforms in Singapore (Lee and Luo, 2006; Tan and Ng, 2005). TSLN is a major reform movement that encourages critical and creative thinking, a radical questioning of old ways of teaching and a valuing of children and their diverse talents. Local teachers, as with their counterparts elsewhere, are hesitant or unsure about the value of implementing some of these new pedagogies despite a host of creative initiatives such as Project Work, School-based Science Practical Assessment, Strategies for Effective Engagement and Development, Learning Circles, generous professional development opportunities for teachers, and physical infrastructures in schools that are world-class.

What we are realizing is that some teachers lapse into familiar transmissive and didactic modes of science instruction albeit now conducted with greater sophistication using technology (Lee, in press). This has resulted in a hybrid situation in Singapore; traditional forms of instruction are entrenched alongside emerging pedagogies (Hogan, 2006; Venthan, 2006). That transition periods are characterized by flux is to be expected although we believe that the progressive momentum in TSLN can stagnate thereby frustrating national attempts at cultivating widespread 21st century knowledge and skills among young people. The sense of ambiguity among teachers and school leaders is tangible for

> **when one considers how central a successful school system is to Singapore's economic strategies...it seems that there is little scope for a radical freeing of the education system and especially the curriculum. (Sharpe and Gopinathan, 2002, p. 163)**

I would now like to share three stories about implementing inquiry science in Singapore.

Helen the Guerilla Science Teacher: A teacher running ahead of the system

Helen, a primary school teacher whom I worked with is an excellent teacher, full of passion for the kinds of discovery learning that inquiry science brings. However, a number of years ago, she was running ahead of the system and her ideas and passion for inquiry science were not appreciated. Let me now tell part of Helen's story in the form of a self-narrated story or vignette.

> **Hi, pleased to meet you, I'm Helen, a fully certified elementary school teacher, and I do use very didactic methods and rely on the textbook. Ok, I lie but let me qualify that. I do use chalk-and-talk but only when the kids request for learning something that's out of the official syllabus. My goodness, I could go on for two hours and everybody's fully alert, no eye is shut. The next day, these kids will come back with their self-initiated research and questions concerning what I've taught, which is simply amazing to read. Textbooks? They're a double-edged sword now. During those times when I ask the kids to bring out their textbooks, they have the cheek to say, "Huh, we're using the textbook?" And I say, "Of course, I have to bring your attention to something important in the book" but they get very disturbed and most of the time they cry, "But we didn't bring any, you never used it before!" Cunning monsters that's what they are, not book smart but street smart!**
>
> **Let me elaborate how sneaky they are. Once, they requested me to teach them powerpoint and winword. I suspected they just wanted to play on the computer but they vehemently denied that and insisted on learning animation and stuff. I told them I would only teach them for an hour because I was rushing to complete the curriculum, and they agreed. Some time later they requested**

> **30 minutes from me to have their "time," which I again thought that they would do something crazy. Boy, did they surprise me when they made an incredible presentation on animals using all the skills that I had taught them! They even had quizzes and candy for prizes at the end, can you imagine that? It was then when I realized that, "Okay, it's worth it after all". In fact, they were getting more and more demanding after being exposed to my teaching methods over the years. You might say that I'm using a lot of open or guided inquiry methods, that I'm very constructivist but I don't care about labels 'coz I think this is how teaching ought to be whether in science or math or whatever. Nobody in my school however is going to stick her neck out and do what I'm doing. When I tell the other teachers that MOE has officially loosened up and encouraged innovative teaching strategies, my colleagues reply, "It's just too risky! I don't want to slip up on the work review. And it's worse when the kids are poor behaved so it is really not worth the effort. Now, it's not that I don't want to give the kids a good education mind you, it's just these other things."**

I think by now you would have realized that Helen was a teacher who was running ahead of the system, pushing for inquiry science when others were not prepared to go this way. She did excellent teaching, but in guerilla fashion, which is what my new article about Helen is all about. This article will be published next year in the Springer journal, *Cultural Studies of Science Education*, where I am one of the editorial board members.

Miss Chen & problem-based learning: A teacher navigating the educational system

Now, the educational climate in Singapore has changed and inquiry science is strongly encouraged. I'm going to tell the story of a high school teacher who attempted to use problem-based learning in her class recently. Problem-based learning (PBL) follows a process whereby groups of four or five students, presented with an ill-structured authentic problem, work collaboratively to generate hypothesis, identify relevant facts, analyze results, and finally present and analyze their findings. As you can immediately see, the process of PBL resembles the inquiry process that scientists use for knowledge creation where scientists use whatever tools and knowledge at their disposal to solve problems (Hmelo-Silver et al, 2007). Well and good, but how does the introduction of PBL look like when first introduced to students more comfortable with traditional didactic modes of teaching?

The following is an excerpt of a transcript from Yeo et al (2006) and shows an exchange in a PBL classroom with the teacher, Miss Chen (MC) and two students, Sandra (S) and Eric.

S:	Basically, protein has four structures.
Miss Chen:	Okay.
S:	That means different protein has different structures.
MC:	At different levels.
S:	Okay.
MC:	Mmm?
S:	At different levels. And basically, the first one is the primary structure, the second one secondary structure, the third one tertiary structure, the fourth one quaternary structure.
MC:	Okay. Tell me about the primary structure.
S:	The primary structure
MC:	**This one ah, time out. This one must know ah.**
Eric:	Okay.
S:	This is a picture of the protein structure.
MC:	Okay.
S:	And it is made up of amino acids.
MC:	Okay. Amino acids.
S:	And is made of a chain of peptide bonds. So if I'm not wrong, these are the peptide bonds, is it? (pointing to the picture on the tablet screen)
MC:	Ya. They just show bonds by lines lah. Essentially, your amino acids like that right? Primary structure focuses on the fact that there are amino acids connected to each other by peptide bonds. Do you know the structure of amino acids? (pause) **Okay, you need to know.**

We observe that the dynamics of this kind of exchange stopped later when the "crux" of the problem was discussed. For example, we see Miss Chen moving the monologue by terse "OKs" as Sandra explained the structure of protein. This elicitation was interrupted at critical junctures whenever important content matter (i.e., the structure of molecules) that was required for the impending examinations was raised. You see, Miss Chen knew the right answers, and she both explicitly and subtly indicated to the students which were the right answers.

We are only showing you this short exchange but we found that at many other places, this kind of marking and flagging of what was tested for the exams were common. These served to indicate, unconsciously, what the real objective of the initial PBL lesson was—content mastery. One particular phrase that stood out was when Miss Chen assured the class during a long debate among the students this statement, "Don't worry, I'll do damage-control later." It basically meant that students could discuss freely however they thought about the problem at that point although the real authoritative source of information from Miss Chen would eventually come later. And the students, being bright people, caught on, and thus waited for Miss Chen's model answer to come later.

The primary conflict here can be attributed to the tension between the exchange value and use value of the object—exam grades (Lave and Wenger, 1991, p. 112). Problem solving skills and metacognition are useful and essential skills in dealing with everyday problems but may not be so crucial in getting by in the high-stakes examinations in Singapore, which test mainly recall and procedural knowledge. In other words, Miss Chen's PBL classroom activity was embedded within a larger system that values good grades in examinations. Although teacher and students worked through the PBL stages, they were very much constrained by the latter and seemingly more entrenched system. What Miss Chen did was to balance, as well as she could, the ideals of authentic learning using PBL versus the demands of a schooling system slowly undergoing change. Underneath the observable PBL approach to science learning lay the "invisible" system that ultimately drove the action of all the participants—teacher and students alike.

Clementi Town Secondary School – A departmental approach to inquiry science

One Singapore school, Clementi Town Secondary School (CTSS), has gone ahead to spearhead an innovative IBL curriculum for all their secondary two pupils (ages 13-14) since 2006. Called ScienceAlive! (Active Learning through Inquiry, inVolvment & Exploration), pupils in Term 3 have the choice of choosing one of four IBL science units in physics, chemistry and biology (Teo et al. 2007). Traditional paper-and-pencil assessment are removed in favor of alternative testing built into the curriculum although the earlier part of the school year follows normal teaching and assessment practices. Explicit teaching of higher-order process skills such as argumentation/reasoning and planning investigations are infused throughout the 10-week program as well as showing pupils the relevance of science in their everyday lives. Active engagement in learning content is further facilitated through laboratory work, field trips, journal writing and group discussions. Similar to other impactful inquiry-based curricula (e.g., Roth and Bowen, 1995), ScienceAlive! culminates in pupil presentations of investigative projects after the 10 weeks.

From teacher conducted pre- and post-course survey and focused interviews, it was found that there was a significant increase in students' perception of skill competency while a high percentage of students indicated that they had increased awareness of the relevance of science for daily life. From these experiments in breaking out of the curricular straightjacket, CTSS was therefore held out as an exemplar for other schools as part of Teach Less, Learn More, which is a new engaged-learning reform by MOE this year (MOE, 2007). Compared to IBL in other countries (see Abd-El-Khalick et al., 2004), this teacher-designed program might not seem remarkable but when we realize that only about 15% of 44 science lessons observed by Venthan (2006) in Singapore schools performed some kind of laboratory experiments, small group work, or demonstrations at some point then the sheer novelty of thoroughly IBL in ScienceAlive! becomes apparent.

Are there problems to be ironed out? Certainly! At the moment, ScienceAlive! is only confined to grade 8 pupils for one term. What has to be empirically established is whether the excellent teaching practices which I have observed in these past few weeks are likewise present earlier in the year. I suspect that they are but this has to be confirmed in 2009 when we follow the teachers through the whole school year by performing the type of research that I like best, a thick ethnographic study of classrooms, long-term participant observations of classroom interactions. While there are plans to introduce similar programs to the grade 7s in CTSS as well as in grades 7 and 8 for other schools, you would immediately realize that Singaporean educators are reluctant to tinker and experiment with introducing IBL to graduating classes where high-stakes examinations loom on the horizon. Similar to Miss Chen's situation, many teachers and parents are understandably concerned about the adequate coverage of subject matter in our very rigorous examination system. Being once a high school teacher myself of graduating classes, I realize that my teaching methods were heavily didactic for these were the most efficient in terms of delivery of subject matter, a power-packed vitamin pill that was just the thing for scoring well! However, I have since repented of my pedagogical sins, and I have now seen the light, I have found inquiry science! Yes, inquiry science is difficult, inquiry science takes time, but we need to know that learning from inquiry science is enduring, it is interesting, and it raises student achievement in the long run.

The Road Ahead for Inquiry Science

Whither inquiry science now? I have illustrated my claim that implementation of IBL is hard by three short case studies in Singapore. I suspect some of these stories of success and difficulties would crop up once schools begin to be really serious about placing inquiry at the heart of their science education programs, whether in Singapore or in the Philippines. Can inquiry science be sustained in the face of all sorts of pressures and resistance from within and without? Let me end by showing three guiding principles, interrelated beliefs that give us a fighting chance of success in planning for a solid grounding in science education.

i. Continue to teach science as inquiry and believe that it works

IBL is really at the heart of science education, we simply cannot continue stuffing the heads of kids with facts. It is more crucial that students know how to think for themselves. We cannot concentrate too much on the memorization of discrete factoids without knowing how all these things fit together. If we think of facts as bricks and big scientific theories or concepts as buildings, then we need to be able to zoom in and out, to see the bricks and the cathedral that the bricks form depending on the need. Unfortunately, school science too often has focused on the bricks thus many young people leave school disliking science or failing to see its big picture relevance (Millar and Osborne, 1998). A piece of good news is that Helen and Miss Chen have not lost faith in IBL, they are now thriving and pressing on with inquiry science in a more committed fashion. Their students like, no love IBL, and the kids have also done well in the exams, which is a vindication that inquiry science will pay off ultimately. And theirs is not the only case I know where these payoffs have occurred.

ii. Search for indigenous solutions and success stories

Change is always difficult, we know that and we've seen how in Singapore the implementation of new curricular initiatives face obstacles and roadblocks. One might therefore legitimately ask whether it is a question of more action/effort by practitioners or more research on the part of researchers to find workable solutions? We would affirm that both are needed but what has been recently identified by MOE as the most vital factor in convincing teachers in Singapore about the long-term efficacy of effective pedagogies such as IBL is the availability of local success stories (Lau, 2007).What is sorely lacking are the local—not foreign no matter how impressive their outcomes—evidence-based research findings showing that IBL actually does work despite the many real or perceived constraints in Singapore schools (e.g., the lack of time, accountability issues, high-stakes assessment regimes, and parental expectations are common discourses). Without these kinds of indigenous breakthroughs and subsequent transformations in practitioners' acceptance of inquiry science, it is felt that our best efforts at science education reforms will be resisted or adopted half-heartedly by teachers. Because teacher adoption of IBL is paramount, having a detailed set of guidelines about how IBL should be taught is no guarantee of success in improving the quality of science education as the US experience has shown (Rutherford, 2005); more so, a better understanding is required of the mediating factors that lead to contingencies and therefore to the uncertainty about success/failure of new curricula in particular settings. Indeed, the problem in Singapore is all the more acute as teaching science via inquiry modes is now being actively promoted at the macro level across all syllabuses and textbooks but so little is actually known in the local literature about IBL implementation. It is likewise the case in the Philippines too I dare say, and I would dearly love to hear these stories so that we in Singapore can learn from you.

iii. Fully support the efforts of local teachers

One of the initiatives recently adopted by the Singapore MOE is "Top-down support for bottom-up initiative." This speaks volumes. I think it signals that change has to come from the bottom, but this change needs a supportive climate and well-positioned champions that are willing to take risks and allow failures to happen. We also know now that the emphasis has shifted from the adaptation of curricula and materials to the strengthening of local capacity and the development of partnerships among institutions. This present assembly is an enlightened one for it brings together scientists, educators and policymakers into one place over a few days for intense face to face discussions. This is knowledge management at its very best, which we in Singapore can profitably learn from.

In Conclusion

Thus, we envisage that teachers need forms of professional development in inquiry science that meet the needs of their community. I acknowledge that the challenges facing urban and rural teachers in the Philippines are vast, at least in Singapore we only deal with one type of school and resource provisioning is not really an issue. At the end of the day, we can be guided from the experiences of others in a similar situation concerning the implementation of new science curricula (e.g., Rogan 2005 in South Africa) but I don't think anybody has all the answers.

Nobody knows the local situation and its problems better than the

Filipino teachers themselves, please listen to them and support them as best as you can, they are your best possibilities in reforming science education! Thank you very much.

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