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Aligning Science Teaching, Learning And Assessment To The I&E Vision

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Abstract

In October 2003, at the MOE Annual Work Plan Seminar, Mr. Tharman Shanmugaratnam, the Minister of Education, highlighted the need to focus on Innovation and Enterprise (I & E) for the next 2-3 years (Shanmugaratnam, 2003). As explained by the Minister, I & E is essentially about a key set of life skills, including mindsets and attitudes that every student must have. I&E in essence is about a mindset and outlook of creativity, initiative and self-reliance. In this author's view, the attainment of "soft" goals such as cultivating a mindset and outlook of creativity, initiative and self-reliance cannot be achieved by stand-alone activities but needs to be supported by the teaching of appropriate content, processes and skills in the core curriculum. It also needs to be supported by appropriate methods of teaching and learning, as well as relevant modes of assessment. In a knowledge-based economy, a strong grounding in science concepts, processes and skills should be considered a pre-requisite for the achievement of the I&E vision. This paper discusses how better alignment could be achieved between the I&E vision and science teaching, learning and assessment.

Introduction

In October 2003, at the MOE Annual Work Plan Seminar, Mr. Tharman Shanmugaratnam, the Minister of Education, highlighted the need to focus on Innovation and Enterprise (I & E) for the next 2-3 years (Shanmugaratnam, 2003). He explained that Innovation and Enterprise (I & E) is essentially about a key set of life skills, including mindsets and attitudes that every student must have, and that I&E in essence is about a mindset and outlook of creativity, initiative and self-reliance. Staff and students with a strong spirit of I&E should possess the following core attributes:

- a. Intellectual curiosity (e.g. to question assumptions, explore and experiment) and ability to see things in new ways (e.g. to recognise patterns and make connections);
- b. Passion, strength of character, perseverance, resilience and ruggedness;
- c. Courage to live with ambiguity (e.g. to seek alternative pathways) and to take calculated risks; and
- d. Sense of teamwork and 'giving back' to the community.

Achievement of I&E vision involves, among other things, the continuous cultivation of a mindset and outlook of creativity, initiative and self-reliance and the creation of a classroom culture conducive for developing I&E habits of mind. Science is a key ingredient in the development of a nation's economy and the achievement of I&E vision

cannot be achieved without developing a sound grasp of scientific knowledge, skills and processes.

Need to align teaching methods and learning approaches to the I&E vision

There is research evidence which indicates that Singapore students lack adequate understanding of science concepts (e.g. Boo, 1995; Boo, 1996; Boo & Toh, 1998a; Tan & Treagust, 1999; Tan et al., 2001), and that inadequate understanding of science concepts is related to the use of inappropriate teaching methods (Driver, 1995) and surface learning approaches adopted by students (Boo & Hoh, 2001; BouJaoude, 1992; Cavallo & Schafer, 1994). A surface approach is associated with extrinsic motivation, where the learner sees the task as a demand to be met and tends to rote memorise terms, facts and procedures. Rote learning requires less effort on the learner's part initially. However, because knowledge thus learned is not well-integrated into the learner's cognitive structure, it is easily forgotten or inappropriately applied. In contrast, a deep learning approach is based on intrinsic motivation where the learner seeks meaning and understanding, and links between new material and existing knowledge. Knowledge which is learned meaningfully is retained longer, better integrated with associated concepts and more readily applied in a wide variety of problems and contexts. According to Novak (1998) only high levels of meaningful learning can lead to creative production. This would suggest that in order to stimulate and enhance creativity in our students, a deep learning approach should be encouraged, and surface learning discouraged.

Research has shown that among the factors that affect students' choice of learning approaches are their epistemological beliefs. Students with empiricist epistemological beliefs (i.e., they view science as relatively static, comprising an accumulation of facts which have been proven correct or true in experiments) tend to be passive and rote learners (Edmondson & Novak, 1993; Songer & Linn, 1991). In contrast students with constructivist epistemological beliefs (i.e. those who view science as dynamic, as a process of constructing predictive conceptual models) tend to engage more in active learning and use deep learning strategies. There is also evidence to show that students' epistemological beliefs not only influence their choice of learning strategies but also their attitude and behaviour toward classroom or laboratory activities (Roth & Roychoudhury, 1993; 1994). For instance, students with empiricist beliefs tend not to try to find out things on their own but to rely on their peers or the teacher to guide them to get things right. This is to be contrasted with students with constructivist views who would tend seek models and principles to explain and integrate their ideas and to generate ideas to make predictions about science (Songer & Linn, 1991).

Another factor which influences students' choice of learning approaches and strategies is teacher's beliefs about learning and knowledge. A teacher's beliefs about learning and knowledge influence the teaching methods and roles s/he chooses to play in class (Benson, 1989; Gallagher, 1991; Hashweh, 1996; Tobin & Fraser, 1988), which in turn impact the classroom climate and the students' approaches to exploration, inquiry, experimentation, articulation and analysis, not only within the boundaries of the core curriculum but also more broadly. Gallagher (1991) for example reported that teachers with positivist beliefs tend to portray science as a body of knowledge and try to cover the content in text books whereas Hashweh (1996) found that teachers with constructivist

beliefs use a wider range of teaching strategies to promote conceptual change and meaningful learning. Where the teaching is teacher-centred or didactic, students tend to learn passively and superficially (Brophy, 1989; Boo & Hoh, 2001; Caprio, 1994). There is evidence to indicate that despite the past decade of change in the educational outlook, the traditional didactic or teacher centred teaching method is still very much alive in our Singapore schools (Toh, 1994; Toh et al., 2003). Teachers' epistemological beliefs influence how they teach, and how they teach influence how students learn.

Thus for I&E to succeed, there is a need to realign teachers' epistemological beliefs from an empiricist or positivist view to a more constructivist view (Boo & Toh, 1998b). This should in turn lead to a switch from traditional teacher-centred teaching to the adoption of a richer repertoire of teaching methods, including constructivist or inquiry-based methods such as problem-based learning (PBL) and cooperative learning. Bodzin and Beerer (2003), describe inquiry teaching as a method that requires students to combine scientific processes and knowledge as they use scientific reasoning and critical thinking to develop their understanding of science. By engaging students in minds-on and hands-on activities, deep learning strategies and discussions on scientific inquiry, they are able to develop an understanding of the various scientific concepts and 'know-how', an understanding of the nature of science, and skills necessary to conduct scientific inquiry. It is shown that a mindset of creativity, initiative and self-reliance can be achieved through inquiry teaching and deep learning approaches and strategies.

Need to align assessment techniques to the I&E vision

A richer repertoire of teaching methods should therefore lead to new learning approaches (i.e. the adoption of deep learning approaches and strategies in place of surface learning ones) which should, in turn, lead to new ways of thinking and application of learned knowledge in novel situations. As new teaching approaches are implemented then assessment techniques must be reviewed and revised to measure the new thinking and learning skills of the students. The use of project work as part of university admission criteria and the replacement of the "single occasion" or once off' science practical examinations at the Cambridge GCE 'O' and 'A' level examinations with SPA (or school practical assessment, where students are assessed on their science practical skills over at least 8 different occasions) should be seen as part of the alignment of assessment techniques to the I&E vision. However, more can be done in terms of aligning assessment to the I&E vision throughout the school system. For example, the preponderance of the traditional four fixed choice multiple choice questions (MCQs) in science examinations at every level from primary three (P3) through secondary four or five (GCE 'O') and pre-university or junior college (GCE 'A' level) is a misalignment to the I&E vision. Such traditional MCQs do not encourage students to think creatively or productively. They are in fact counter-productive to the I&E vision and could disadvantage students who are capable of lateral thinking or have developed creative thinking approaches. Two specific examples from primary science examination papers will be discussed to illustrate what is meant.

Traditional MCQ -Example 1

Level: P3

Which one of the following animals is **unlike** the others in terms of how it moves?

- 1 frog
- 2 kangaroo
- 3 rabbit
- 4 tiger

Comment on the above MCQ

In this question, the question setter's intended answer is option 4. To the setter, who has taught students the topic of "animals and their movement", the given item is a very easy one, almost a give-away, since "tiger" does not hop while the others do. However, students, especially the creative ones, probably could see alternatives not seen by the setter and the non-creative students, and could choose any of the other options as the answer.

- Option 1 could be the answer key since the "frog" is the only animal that can swim underwater.
- Option 2 could be the answer key since the "kangaroo" is the only animal that uses only two legs when moving at optimum speed.
- Option 3 could be the answer key since the "rabbit" is the only animal that can burrow or move underground.

Traditional MCQ -Example 2

Level: P5

Which of the following is the result of the Earth's revolution around the Sun?

- 1 the change of seasons
- 2 the change of weather
- 3 the change from day to night
- 4 the change of the moon phases

Comments on the above MCQ

In this question, the setter's intended answer is option 1. However, some students could reason from the perspective that as the seasons change, so does the weather. Therefore option 2 is also correct. Option 3 could also be correct if one considers that if earth spins about its axis and does not revolve round a heavenly body which emits its own light (such as the sun), then there would not be day and night at all. For this question, most of the "examination-smart" students or those who rote learn or

memorise bits of information from the textbook would choose option 1 as the correct answer and be marked correct. However, those who think more laterally or deeply would consider options 2 and 3 correct as well, and if there are no provisions for them to explain their thinking, then they could either be marked wrong for having chosen an option that is different to that of the setter's or could end up feeling frustrated or discouraged from learning science.

Thus such traditional MCQs may hinder the development of creativity and are unfair to students who are capable of creative or lateral thinking. It is a significant challenge for question setters to be able to anticipate all alternative perspectives or viewpoints in students, especially the creative ones.

Further potential problems associated with the extensive use of traditional MCQs have been identified by Black (1998). He suggests that they would probably not give a fair indication of the capacity of students to succeed in any future study of science. Also, heavy or exclusive reliance on MCQs in high-stakes tests can lead to emphasis in teaching to the test, an atomized approach to learning (i.e., surface learning), and to a passivity in which one judges other people's ideas but does not propose, formulate or create ideas of one's own. These negative habits of mind highlighted by Black are detrimental to our goal of achieving the I&E vision.

According to Guilford (1986p. 3-4), using traditional MCQs to test creative students (the creators) in which all they need to do is to select an appropriate option as the answer and without having to formulate their own ideas, may prevent them from showing precisely what we want them to show: their own creation. He also suggests that our quest for easily objectifiable testing and scoring has "directed us away from the attempt to measure some of the most precious qualities of individuals and hence to ignore those qualities."

Ideally a range of assessment techniques including paper-pencil ones (such as free response or open-ended questions, concept mapping and so forth) as well as practical-based ones (performance assessment such as SPA and project work) should be used in evaluating student learning outcomes. However, such changes in assessment involve several challenges, among which are those that concern logistics and training of teachers and assessors and could take some time to implement. Whilst MCQs are still seen as useful in terms of assessing learning outcomes, it is suggested that a two-tier MCQ (which involves adding an open-ended segment to each existing MCQ – see specific examples below) be used in place of the standard or traditional MCQ. This would ensure that the perspectives of creative students are taken into consideration during marking. It would mean that a longer time would be spent in the marking; however, this additional "cost" in time taken can be justified in terms of the gains that could result from its positive contribution in taking into account the creativity of students.

The first tier of a question, labelled as part (a), comprises a stem with four options from which students are to select one, more than one or none of the options as their answer. In the second-tier, labelled as part (b), they will be asked to explain the reasoning behind the selection of option(s) in part (a).

Previous example questions reformed as two tier MCQs

The following instruction is given at the head of the paper or section:

Read each of the following questions carefully. In part (a) state which one or more of the 5 given options are possible answers and explain your reasoning in part (b). If you think none of the given options are appropriate answers, explain why and provide your own answer. Parts (a) and (b) of each question together is worth 2 marks. One extra bonus mark will be awarded for answers which demonstrate a deeper understanding of the topic or underlying science concepts.

Two-tier MCQ - example 1

<p>Which of the following animals is unlike the others in terms of movement?</p> <ol style="list-style-type: none">1 frog2 kangaroo3 rabbit4 tiger5 none of the above <p>(a) State your choice of the option(s).</p> <hr/> <p>(b) Explain your reasoning.</p> <hr/> <hr/> <hr/> <hr/> <hr/>

Two-tier MCQ - example 2

<p>Which of the following is the result of the Earth's revolution around the Sun?</p> <ol style="list-style-type: none">1 the change of seasons2 the change of weather3 the change from day to night4 the change of the moon phases5 none of the above <p>(a) State your choice of the option(s).</p> <hr/> <p>(b) Explain your reasoning.</p> <hr/> <hr/> <hr/> <hr/>
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Marking Scheme for two tier MCQ

In both the examples given, in part (a), if the student gives the answer which matches that given in the mark scheme then s/he is awarded 2 marks and part (b) of the answer will not be marked. This means that no marks will be awarded for correct reasoning and no penalty will be imposed on incorrect reasoning given in part (b).

If the student selects an option in part (a) which differs from that given in the mark scheme, then his/her part (b) answer will be scrutinised. If part (b) answer correctly justifies his/her choice of answer in part (a), then 2 marks will again be awarded.

If the student demonstrates creative or lateral or divergent thinking with clear explanations of his/her reasoning, such as by stating that there is more than one possible answer (and his/her answer could be "2 possible answers...." or "3 possible answers....") and provides plausible reasons in part (b) for his/her choice of answers (examples of which are included in the preceding section, then s/he scores 3 marks. The third mark is a bonus mark.

A possible alternate approach that would further shift the balance of marking towards assessment of thinking skills would be to award 1 mark if the answer to part (a) matches the model answer and the second mark only if the answer to part (b) is a reasonable explanation. Not only would this more effectively measure the deep approaches but would also remove some level of formalised support for guesswork which is a major criticism of the traditional MCQ. Thus by allowing students to choose none or one or more than one of the given options as the correct answer and by allowing them to explain their reasoning, the higher order thinking power of students can be assessed.

This marking strategy could then be followed through with analysis of marks distribution between the two tiers to more accurately understand which students are displaying the desired learning approaches.

Conclusion

Teacher's epistemological beliefs affect their choice of teaching methods and the role they choose to play in the classroom. These in turn affect students' epistemological beliefs, their choice of learning approaches and strategies and the quality of their thinking and learning. Creativity, initiative and self-reliance are outcomes associated with deep learning approaches and strategies, which are in turn associated with constructivist or inquiry teaching and learning. To achieve the I&E vision would require a mindset change on the part of many teachers – to change from a positivist or empiricist outlook to a more constructivist outlook which in turn should lead to a change in the teaching methods – from generally passive teacher-centred methods to active inquiry-based methods (including a repertoire ranging from cooperative learning to problem-based learning or PBL). New ways of thinking and learning will require corresponding changes to assessment techniques, to probe and to assess student thinking and production of new ideas and their success in integrating new concepts into their knowledge base and thinking processes.

There is extensive evidence that 'high stakes' testing constrains both teachers and students to align their learning to meeting the demands and expected results of tests. As suggested by (Beetlestone, 1998) it could be argued that young children start off as divergent thinkers and gradually become more convergent thinkers as they mature and are socialized into specific patterns of response. Some of the tools included in the socialization process include traditional or standard MCQs used in school tests and examination papers.

External tests can be powerful influences on teaching and learning (Black, 1998 p.45): Whether these influences are evaluated as beneficial or not will depend on the qualities of the test and the assumptions about learning adopted by the evaluator. As suggested by Resnick and Resnick (1992 p. 59), assessments must be so designed that when you do the natural thing – that is, prepare students to perform well – they will exercise the kinds of abilities and develop the kinds of skills that are the real goals of educational reform. If we value creative and innovative thinking, risk taking and a spirit of entrepreneurship among our students, then we need to align our methods of testing to our goals of achieving the I&E vision. Among the changes needed is a shift to more open ended assessment items such as the modified form of two-tier MCQ discussed in this paper. As historian Toynbee (1967 p.4) observed, "To give a fair chance to potential creativity is a matter of life and death for any society". This statement is truer of our society than others considering our paucity in natural resources and the fact that our only resource is human resources.

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