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THE DISTINCTIVENESS AND EFFECTIVENESS OF SCIENCE TEACHING IN THE MALAYSIAN 'SMART SCHOOL'

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Abstract: A recent reform initiative in the Malaysian educational system has sought to develop 'Smart' schools, intended to better prepare students for adult life in a developing economy and to increase the flow of young people prepared for scientific and technological careers. The study reported in this paper examined lower-secondary science teaching, comparing two Smart schools officially judged to be successfully implementing the reform, with two neighbouring Mainstream schools. Through analysis of classroom observation, supported by teacher interview and student report, the distinctive features of science teaching in the Smart schools were found to be use of ICT-based resources and of student-centred approaches, often intertwined to provide extended support for learning; accompanied by a near absence of the note giving and copying prevalent in the Mainstream schools. Through analysis of measures of student attitude to science, science process skills, and general science attainment, science teaching in Smart schools was found to be relatively effective overall. However, while the positive attitude effect was general, both academic effects were much weaker amongst students who had been of lower attainment on entry to secondary school.

Keywords: educational reform; Malaysia; science education; smart school; teaching methods; technology integration

Introduction

In developing nations, educational improvement is widely perceived as a vehicle for economic development and industrial modernisation (Benavot 1992; Brown-Acquaye 2001; Walberg 1991). Malaysia exemplifies an approach in which government policy has coupled educational and industrial development, aiming to enhance the country's scientific and technological capacity so as to achieve fully developed status by the year 2020. A central policy goal has been to strengthen educational provision with a view not just to raising levels of attainment and participation but to increasing the proportion of students following science-based options in upper-secondary and higher education to achieve a ratio of 60:40 for science-versus arts-based students.

Over recent years, a key policy mechanism for this educational transformation has been the Smart Schools Initiative which envisages a close coupling of educational and technological development. Indeed, the Initiative forms part of a broader project to create a Multimedia Super Corridor [MSC] in Malaysia, in the expectation that rapid development of the MSC infrastructure and increasing deployment of leading-edge technologies will play an important enabling function for the wider educational changes proposed for Smart schools. This expectation might be regarded as optimistic in the light of findings that, at the classroom level, such development does not unfold readily, particularly in secondary schools and in more academic subjects (Cuban, Kirkpatrick, and Peck 2001; Ng and Gunstone 2003; Tan, Hedberg, Koh, and Seah 2006). Indeed, the Director of the Curriculum Development Centre of the Malaysian Ministry of Education has acknowledged many challenges to be overcome (Zin 2003).

The spearhead for the Smart Schools Initiative has been a cohort of pilot schools, established in 1999, and intended to serve as the nucleus for eventual system-wide reform (Smart School Project Team [SSPT] 1997). Within policy discourse, the development of

Smart schools has been conceived in pedagogical terms that appeal to successive – and not necessarily compatible – waves of educational reform philosophy in developed countries. These pilot schools and their teachers have been charged with interpreting the multifaceted pedagogical aspirations embraced by the policy discourse of Smart schooling and translating them into viable classroom practice.

Focusing on science education in the lower-secondary phase, the study reported in this article examines this emergent Malaysian reform in operation. First we sketch the curricular background to the reform, and outline the key strands of pedagogical thinking embraced by official guidance on science teaching at lower-secondary level. Then we report a study designed to investigate what is distinctive about classroom practice in schools which are officially judged to be implementing the Smart school reforms successfully, and how effective that practice is.

Post-independence development of Malaysian school science teaching

School science education began in Malaysia during British colonial rule. During this period, the education system was highly elitist, with only a small percentage of each age cohort being selected to proceed to secondary level where formal science education was provided. There, the subject was generally taught by expatriates, and students used imported textbooks and sat for the same Cambridge examinations as their counterparts in England. Following independence, and the establishment of the new state of Malaysia in 1963, a more inclusive system of education was created with a common language (Bahasa Malaysia) as the main medium of instruction, a national curriculum and examination system, and a largely indigenous teaching force (Wong and Ee 1975). A national Curriculum Development Centre [CDC] was established in 1973 to oversee matter pertaining to curriculum adaptation and adoption.

Nevertheless, curricular reforms at secondary level continued to reflect a strong British influence (Zainal, 1988). During the 1960s and 1970s, the emphasis of these reforms was on (i) integration and (ii) relevance of the science curriculum, and on (iii) science process skills (Nielsen, 1985). Contemporary research found only partial implementation of these reforms at classroom level (Lewin 1975; Sim 1977; Zainal 1988). In particular, studies reported that teachers modified the inquiry strategies envisaged by the reformed courses, or ignored them, continuing to use an essentially transmissive pedagogy. Amongst the reasons cited were: (i) lack of confidence and competence on the part of teachers to try out new teaching techniques, probably due to their poor grasp of the subject-matter and poor training; (ii) physical constraints in terms of class size and facilities; (iii) social pressure to teach towards examinations; and (iv) a cultural context where respect for authority inhibits independent and critical thinking (Lee 1992). These precedents underscore the central role of teachers in mediating reform efforts.

A further wave of reform led, in 1988, to the Integrated Curriculum for Secondary School (*Kurikulum Bersepadu Sekolah Menengah*) [ICSS], which continues to provide the basis of secondary science programmes. Alongside development of scientific knowledge and skills, ICSS Science also emphasises the inculcation in students of social values and positive attitudes to science.

Defining characteristics of the Malaysian 'Smart School'

The Malaysian Smart School Initiative appropriated a term already being employed elsewhere (Gan 2000; Perkins 1995). The official characterisation of the Malaysian Smart School is as an institution under continuous reform:

> "… a learning institution that has been systematically reinvented in terms of teaching-learning practices and school management in order to prepare children for the Information Age. A Smart School will evolve over time, continuously developing its professional staff, its educational resources, and its administrative capabilities. This will

> allow the school to adapt to changing conditions, while continuing to prepare students for life in the Information Age." (SSPT 1997, 10).

In more specifically educational terms, such a school aims to provide experience that:

> "… stimulates thinking, creativity, and caring in all students; caters to individual abilities and learning styles; and is based on more equitable access. It will require students to exercise greater responsibility for their own learning, while seeking more active participation by parents and the wider community." (SSPT 1997, 9).

The educational approach advocated in the Smart school reform documents shows a strong influence from Perkins' (1995) original conception of a 'smart school' as one employing educational approaches informed by new perspectives in cognitive science, and responsive to social needs for deeper learning. Echoing the four levels differentiated in Perkins' discussion of pedagogy of understanding, the Malaysian Smart School explicitly aims to develop "content knowledge, problem solving knowledge, epistemic knowledge, and inquiry knowledge" (SSPT 1997, 31). Likewise, the Initiative's emphasis on explicit teaching of skills for creative and critical thinking resembles Perkins' notion of metacurriculum. Moreover, in line with Perkins' emphasis on the physical, social and symbolic distribution of intelligence – in particular as supported by new information and communication technologies – the Initiative envisages such technologies helping to "combine the best of network-based, teacher-based and courseware materials" (SSPT 1997, 58), for example through "every computer… hav[ing] access to the latest educational materials available locally, as well as to external resources" (*ibid.*, 102).

Nevertheless, in overlaying newer reform ideas on earlier ones, the Malaysian Smart School Initiative introduced potential philosophical and practical tensions. For example, official guidance advocated both constructivist practice and mastery learning, without clarifying how these differing and sometimes discordant orientations might be reconciled in a coherent pedagogical approach. Equally, the detail of reform ideas and their operationalisation was often underdeveloped. For example, official guidance provided only short generalised descriptions of IT-enabled approaches in science teaching, such as use of simulation, modelling, and computer-assisted experimentation to teach certain concepts. In many respects, then, the Smart Schools Initiative has been an emergent reform.

Officially recommended practice in Malaysian science teaching

The reform ideas associated with science education in the Malaysian Smart School were intended to be compatible with existing policies, representing extensions and enhancements to them rather than revisions. For example, Smart schools continued to teach to the same curriculum specification as (what we shall term) Mainstream schools, and to prepare their students for the same external examinations. It will be helpful, then, to review some central features of officially recommended practice for science teaching in Mainstream schools, and key extensions in relation to Smart schools.

Constructivist teaching

The science syllabuses for both types of school emphasised that planning for teaching and learning should “tak[e] into account students’ prior knowledge” because meaningful learning occurs when students “restructure their existing ideas by relating new ideas to old ones” (CDC 1999, 12; CDC 2002a, 12). A guidebook on “Learning by means of Constructivism” (*Pembelajaran secara Konstruktivisme*), published and disseminated to all schools by the Curriculum Development Centre (2001a), aimed to provide teachers with exemplary constructivist lessons: a common feature of these lessons is creating opportunities for students to reveal their pre-instructional views.

Mastery learning

A handbook on “Mastery Learning” (*Pembelajaran Masteri*) (CDC 2001b), produced and disseminated to all Smart and Mainstream schools, outlined some features of this approach:

notably that “the learning outcomes are arranged in a hierarchy of learning units; students should master 80% of the mastery level set for each learning unit before moving to a new learning unit; remedial activities should be conducted for students who failed to reach the mastery level; and enrichment activities should be conducted for students who have reached the mastery level” (p. 3). However, while the syllabuses for both types of school specified the same set of learning objectives, the Smart science document detailed each learning outcome at three levels such that “L1 is a pre-requisite to L2, which in turn, is a pre-requisite to L3” with the three levels intended to be taught “sequentially” (CDC 1999, 15).

Science process skills

The guidance for both types of school placed similar emphasis on science process skills (CDC, 1999, 2002a). The 12 science process skills that “enable students to question a certain phenomenon and to find the answer in a systematic fashion” (CDC 1999, 7) were explicitly identified and defined in the relevant syllabuses: observing, classifying, measuring and using numbers, inferring, predicting, communicating, using space and time relations, interpreting data, defining operationally, controlling of variables, hypothesising, and experimenting.

Thinking skills and metacognition

The science syllabuses for both types of school categorised thinking skills into “critical thinking skills, creative thinking skills, and thinking strategies” (CDC 1999, 3). These categories were further demarcated, defined, and elaborated in a supplementary curriculum handbook, entitled “Thinking Skills in Teaching and Learning” (CDC 2002b). This same handbook treated “metacognition” (CDC 2002b, 53) in terms of students being aware of how they think, methods they have used to explore different approaches in solving a problem, and the learning experiences that they have undergone. However, the Smart School Initiative strongly emphasised the infusion of “critical analysis and evaluation, decision making, problem solving, and creative thinking skills" (Smart School Project Team 1997, 33) into the curriculum in an integrated manner.

Student-centred learning

The official guidance for science teaching in both types of school endorsed student-centred approaches to learning, although it also indicated that not all learning should be student-centred because some concepts or principles within each level are more appropriately delivered "by the teacher or by assisted inquiry" (CDC 1999, 12). At a more general policy level, however, the Smart School Initiative envisaged learning objectives being selected by students with their teacher's suggestions and input, and likewise the instructional tasks and resources (SSPT 1997, 39).

Self-directed, self-paced and self-accessed learning

Consequently, three salient elements of student-centred learning advocated for Smart schools were self-accessed, self-paced, and self-directed learning. Here the student role becomes a more active one in shaping the pattern of learning. In self-directed learning, "responsibility [is given] to learner for directing and managing [his/her] own learning" (SSPT 1997, 40). The guidance recommended that "increasing student control [should be in step] with increasing age and maturity" (SSPT 1997, 44). ICT is viewed as a key enabler of self-accessed learning, allowing students to "collect, analyse, process and present information" (SSPT 1997, 37). Equally, the use of ICT was suggested to "facilitate self-directed learning" (CDC 1999, 14) and to "facilitate… self-paced learning which subsequently, allows for vertical integration… to happen in our educational system" (CDC 1999, 14). By contrast, guidance for Mainstream schools contained no mention of self-accessed, self-directed and self-paced learning.

Here, then, official guidance and provision for the two types of school were more sharply distinguished. There was a similarly sharper demarcation for one further feature.

Use of information and communication technology

For both types of school, official policy advocated use of information and communication technology (ICT) in science teaching. Within the Mainstream curriculum specification for science (CDC 2002a), the focus was on scientific simulation and instrumentation: "computer simulation and animation are effective tools for the teaching and learning of abstract or difficult science concepts…[and] the use of… data loggers and computer interfacing in experiments and projects also enhances the effectiveness of teaching and learning of science" (ibid., 15). Within the Smart specification, ICT was also presented in broader terms "as a vehicle to optimise learning outcomes. Examples of ICT were the use of television, radio, video, computer software, course software, internet, [and] teleconferencing (CDC 1999, 14). In particular, however, Smart schools benefited from a substantial investment in ICT infrastructure and resources not available to Mainstream schools.

Design and organisation of the study

Bearing in mind the way in which the unfolding of educational reform is shaped by the sense-making of the agents involved (Spillane, Reiser and Reimer 2002), the study to be reported here sought to understand the distinctiveness of the model of science teaching actually being realised in Smart schools, as well as to assess its effectiveness. From official evaluations conducted while this study was being designed, it had also become clear that quality of implementation was very variable between institutions.

This study, then, set out to examine examples of what was officially judged to be the best available practice to be found amongst the 46 non-selective neighbourhood secondary schools then designated as Smart schools. To gain access to schools, and secure the cooperation of teachers, it was also expedient to carry out the study in the region of Malaysia where the first author was professionally active. Two Smart schools – one in Penang, one in

Perak – were recommended by officials in the Ministry of Education on the basis of reports from on-site monitoring of science teaching in Smart schools as part of a national evaluation; this had led to science teaching in these schools being ranked 1st and 5th respectively in the evaluation, with both (what we shall refer to as) SS1 and SS2 rated as meeting the criterion that "teachers operationalised Smart teaching and learning of science well and successfully", and SS2 rated as approaching the further criterion that "teachers operationalised Smart teaching and learning of science in an excellent manner and seemed to internalise it in their daily pedagogical practice".

To provide a benchmark for comparison, a non-selective neighbourhood Mainstream school nearby to each Smart school was chosen, with a student body of similar composition by race, gender, and socio-economic status. These two Mainstream schools (which we shall refer to as MS1 and MS2) were intended to provide comparators both for understanding the *distinctiveness* of science teaching in Smart schools, and in assessing their *effectiveness* in promoting key student outcomes. It should be noted that, in Malaysia, placement of students in non-selective secondary schools is arranged by the respective District Education Offices on the basis of catchment area. Indeed, students in the cohort examined in this study had already been allocated to secondary schools before their designation as Smart schools.

The study focused on the student cohort entering Form 1 of secondary school for the 2001 academic year, progressing to Form 3 for the 2003 academic year, and taking the Standardised National Examination on completion of their lower secondary education at the end of that year.

The *distinctiveness* component of the study was conducted during Term 1 of the 2003 school year. In each school, three Science classes were chosen for observation – the highest set, the median set, and the lowest set – making for a total of 12 classes, typically of just under 30 students. As there were only two – or in one case three – teachers of Form 3 Science in each school, all were included in the study, in their capacity as teacher of at least one of the sets chosen. Two lessons taught to each of the chosen classes (avoiding lessons involving revision or testing) were observed (and audio-recorded to complement the structured field-notes made) and the class teacher was subsequently interviewed (and audio-recorded). For the purposes of reporting results each of the nine teachers has been given a unique letter identifier followed by their school identifier.

The main concern of the protocol for classroom observation was with identifying and documenting episodes during which one or more of the officially recommended elements of science teaching (as already outlined in the preceding section) was in play. The main concern of the protocol for teacher interview was with eliciting teachers' assessments of the degree to which they employed each of these named elements of science teaching, and with their providing illustration of such elements where appropriate. A final instrument sought to capitalise on students as observers of their own science lessons: a Smart Science Learning Experience Inventory [SSLEI], again based on officially recommended elements of science teaching, was developed in questionnaire form and administered to all students in the study cohort (Ong and Ruthven 2003; 2004).

While the teacher interview and student questionnaire did provide some useful insights, by far the most important of these was that the official discourse of science teaching was quite distant from the language and experience of both teachers and students. Primarily for that reason, it was the classroom observations which proved most illuminating, with the other data sources providing useful triangulation. In following the field-note protocol for classroom observation, the official elements defining focal issues had been interpreted liberally, resulting in a good range of episodes being documented as well as the classroom exchanges audio-recorded. This enabled the analysis to develop a new set of themes, better matched to the episodes observed, and informed by the ways in which teachers described their practice and construed key elements of official discourse. During the period when observations took place, the science topic being taught to Form 3 in all the schools was ‘reproduction and growth’. On the one hand, this uniformity of topic is helpful for purposes of comparison; on the other, the singularity of topic imposes a degree of caution in extrapolating findings.

The *effectiveness* component of the study involved all Form 3 students on roll in the four schools during the 2003 school year: around 240 in each of MS1 and SS1, and around 140 in each of MS2 and SS2. To assess student attitudes to science, an existing instrument, ATSSA(M) (Lau 1997) – the Malay version of Germann’s (1988) well-established Attitudes Towards Science in School Assessment (ATSSA) – was validated (Ong and Ruthven 2002). Likewise, to assess students’ science process skills, TIPS-II(M) – the already validated (Ismail 2001; Zurida and Ismail 1996) Malay version of Burns, Okey, and Wise's (1985) well-established Test of Integrated Process Skills II – was employed (Ong and Ruthven 2005). Because of local concerns that students should not be distracted during the extended period of preparation for the Standardised National Examination, these instruments were administered earlier in the school year. Finally, students’ grades in the Science component of the Standardised National Examination were used as measures of general science attainment: the grade awarded at the end of primary school, before entering Form 1, as a prior measure; and the grade awarded at the end of Form 3 as an outcome measure. At both levels, these attainment measures have an emphasis on factual knowledge in science.

The distinctiveness of Smart science teaching

Before reporting on what was distinctive about Smart science teaching, it is important to emphasise that classroom observation (supported by teacher interviews) identified a number of similarities with science teaching in Mainstream schools. In particular, these involved similar patterns of interpretation of official guidance. Two of the most important will be briefly summarised here, because they illustrate how such guidance was open to alternative interpretation and limited implementation in both types of school.

Similarities in interpretation and implementation of official guidance

Across all four schools, the idea of taking account of students' prior knowledge was interpreted and enacted in two ways, both rather different from the emphasis on bringing out students' preconceptions associated with the official idea of Constructivist Practice. One interpretation involved drawing on students' everyday knowledge and experience of natural phenomena to anchor the introduction of a related scientific concept. For example, CMS2 invoked students' own experience of having many burrs (*kemuncup*) sticking to their clothes when they played in the school field, while she was trying to explain the use of animals as agents of dispersion. Equally, ESS1 appealed to students' experience of seeing a newborn baby in the bath when she wanted to describe the foetal position in the uterus. The other interpretation involved reactivating students' knowledge of earlier curricular material. For example, AMS1 reviewed with students their previous learning on asexual reproduction, and GSS2 called on students to answer a series of questions to review development of fruits (from zygotes) and seeds (from ovary).

Some promotion of science process, thinking and metacognitive skills was present across all four schools. The process skills observed under development were rather limited, typically interpreting data from a graph. Only one teacher, was observed to conduct practical work with his students, where they investigated the structure of a hibiscus and *Semarak Api.* Inculcation of a wider range of thinking skills was in evidence, in the form of comparing and contrasting (i.e., the differences between an ovum and a sperm); using class and group discussions, columned tables, and graphic organisers; generating ideas through the use of mind maps and brainstorming to capture the key points of a concept; and predicting. Incorporation of some form of metacognition was observed only in one lesson (in SS1) where students were asked to write down what they had learnt, what they knew as a result of the lesson that they did not prior to it, and what they liked about the lesson.

Giving and copying notes

We now move on to identify key differences between the classroom practice observed in the two types of school, and so what was distinctive about the science teaching in the Smart schools. We start with a type of activity that was prevalent in the Mainstream schools, and rare in the Smart schools: note giving by the teacher and/or note copying by students. In the Mainstream schools this occurred in 11 of the 12 lessons observed (and featuring all of the teachers), compared to 2 of the 12 in Smart schools (both taught by the same teacher). The summary of note giving and copying episodes in Table 1 shows that many were lengthy.

Note-copying episodes ranged from students' copying written notes from the blackboard, textbooks or teacher dictation, copying diagrams and figures from the blackboard or textbooks, to copying answers to workbook questions as dictated by the teacher. Although some teachers described such note-copying activities as "student-centred learning" in the teacher interviews, they seemed a very poor fit to the official model of student-centred learning which advocated involving students in resource selection, and in synthesising and making notes on key ideas.

[INSERT TABLE 1 HERE]

Using ICT resources

Smart schools provided an environment that was more technologically enriched than that of Mainstream schools. As shown in Table 2, no use of ICT resources was observed in any of the lessons in Mainstream schools, whereas it featured in 5 of the 12 lessons in Smart schools, used by 4 of the 5 teachers. The Smart school teacher who was not observed to use ICT confirmed in interview that she very rarely did so. This reflected a difference in policy between the two Smart schools: whereas, in SS1, use of ICT was left to a teacher's discretion and level of confidence, in SS2, such use was mandatory.

[INSERT TABLE 2 HERE]

When teachers in the Smart schools used ICT, they aimed to do so in ways that would be interesting, motivating and illuminating to students. One strategy employed graphics and animations to enhance students' understanding and grasp of scientific phenomena. An episode from a lesson (cf. JSS2/3K5/[1]) in which a student clicked on the hypertext on "process of embryo development" to watch an animation of an embryo developing into a foetus and then to a baby, culminating in the delivery process, showed how illuminating animation could be in fostering a better grasp of the phenomenon under investigation. The excerpt in Table 3 shows a low-achieving boy exploring an animation.

[INSERT TABLE 3 HERE]

Additionally, teacher-led science lessons using software presentation on a large screen held students' attention and prompted good responses through the combined effect of teacher encouragement and software qualities such as visualisation and graphical representation.

Teaching about the difference of growth rate in boys and girls, a teacher from MS2 referred students' attention to a table in the textbook that tabulated the average heights of girls and boys from birth to the age of 18 (CMS2/3C/[1]). Drawing two axes of height against age on the blackboard, different students were called to graph each set of data (i.e., coordinate of age and average height) by placing a dot on the axes. Teaching a similar concept, a teacher from SS2 employed technology to enhance investigation of the different growth rate between boys and girls (HSS2/3K3/[1]). The data on average height for boys and girls from birth to 18 years had been pre-loaded in a spreadsheet and were amenable to changes and manipulation. Then the teacher presented the two contrasting lines on the screen using different colours. There followed a rich discussion in depth of the graph. Students were able to deduce that the steeper the graph, the faster or higher the growth rate, and to fruitfully identify places (i.e. ages) where more rapid growth occurred.

Work presentation was also enhanced, exemplified by students publishing their work and reports and presenting them to their teachers and peers. Additionally, giving each student an electronic mail account so as to enable them to communicate among themselves and with teachers and staff within the school encouraged sharing of information, as observed in one lesson (c.f. JSS2/3K5/[1]).

Extended support for learning

While teachers in both Smart and Mainstream schools supported students' learning of science through teacher and class discussion, and through action-based student learning activities, support for learning by students in most classes in the Smart schools was extended in several ways. As shown in Table 4, such extended support came from sources other than teachers and textbooks.

Distinctive peer support was perceptible in the Smart schools through the use of interaction-based learning – a subcategory of student-centred learning that emerged from the teacher interviews. Putting students in expert groups to study assigned topics in depth and later to present their topics (GSS2/3K1/[2]) produced student-student interaction capable of fostering positive interdependence within groups (i.e., members in each group support one another in learning the assigned material) and between groups (i.e., the learning of a particular topic by members of other groups depends on the presentation of that topic by the group assigned to it). Structuring pair work at computer terminals and assigning each member of a pair a complementary or interconnected role, as observed in one lesson (FSS1/3T3/[1]), was similarly productive. In the first part of the lesson, students were assigned to navigate "reproduction" in order to complete a graphic organiser worksheet that compares a sperm cell and an ovum. Here, students in each pair were assigned either as a so-called clicker (i.e., clicks with the mouse) or recorder (i.e., writes the answer on worksheet). In the one example of group-work observed in a Mainstream School (AMS1/3A1/[1]), with students naturally gathered or seated at benches because the lessons were conducted in the science laboratories, there was no deliberate attempt to structure group work, and there was little evidence of student-student interaction that might promote co-construction of knowledge.

[INSERT TABLE 4 HERE]

The technology-enriched environment provided in the Smart schools also contributed to extended support for more perceptibly self-directed, self-paced, and self-accessed learning. While the overarching topic was usually teacher-specified, students were able to choose and pick a learning task from the available range of activities to work on, contingent upon their current level of ability and interests. Additionally, students were able to work on the learning task, individually or jointly, progressing at their own pace. Substantial episodes of this type were observed in 5 of the 12 lessons in Smart Schools, involving 4 of the 5 teachers (mirroring the pattern of teacher use of ICT). A lesson which exemplifies this had reproduction as its overarching topic (JSS2/3K5/[1]). In this lesson students were seen accessing different learning activities according to their own interest and pace. One boy was accessing the learning materials on “analysing human reproduction and conception”, taking a microscopic view of an ovary and watching an interesting animation on embryo formation. Meanwhile, another student was accessing “application of vegetative reproduction on flowering plant”; within a short period he switched his interest to “the process of embryo development”, exploring the text and watching the animation on amniotic fluid, embryo, and placenta. He then answered the online questions posed. A further student looked at the multimedia content for “analysing the female reproductive system” showing an animation of a girl growing into her puberty stage. Yet another two boys each accessed a different aspect of reproduction, namely “analysing the menstrual cycle” and “analysing the dispersion of seeds”.

The effectiveness of smart science teaching

The effectiveness of Smart science teaching was examined by analysing student performance on three outcome measures relating to attitude towards science [ATSSA(M)] (reported fully in Ong and Ruthven 2009), science process skills [TIPS-II(M)] (reported fully in Ong and Ruthven 2005), and general science attainment [SNE in Science at the end of lower secondary education] (reported fully in Ong 2004). In conducting these statistical analyses (of covariance), the prior measure of general science attainment [SNE in Science at the end of primary education] was used as a covariate. To cross-check results, analyses were conducted not just by school-type (Mainstream v. Smart) but by individual school (MS1 v. MS2 v. SS1 v. SS2), confirming that the findings were robust. In addition, separate comparisons were made for students at each entry grade to secondary school (from the highest, A, through to D; but excluding the lowest, E, because there were few students at this level). The results are summarised in Table 5.

The results show aggregate differences in all three student outcomes favouring the Smart over the Mainstream school type, with a large effect size for attitude to science, and moderate effect sizes for science process skills and general science attainment, all of which are highly statistically significant. In interpreting these results, of course, it must be remembered that the Smart Schools participating in this study had been deliberately chosen because they were officially regarded as amongst the best of their type in terms of their implementation of the reform teaching model, whereas the Mainstream Schools had not been selected in any similar way.

[INSERT TABLE 5 HERE]

However, more detailed analysis suggests that, in terms of academic outcomes, the science teaching found in the Smart schools was differentially effective according to students' entry grade from primary school. As the final column of Table 5 shows, while the attitude effect extends across students regardless of entry grade, the process and attainment effects are much stronger amongst those students who had entered secondary school with average to higher entry grades, C through to A. Neither our lesson observations nor student reports identified marked differences of teaching approach between lower, average and higher sets; this suggests that the same types of classroom experience which gave rise to more effective learning on the part of higher- and average-achieving students were less accessible to, manageable by, or productive for their lower-achieving peers, both as regards process skills and factual knowledge in science.

Conclusion

The findings of this study can be summarised as follows. First, the influence of these reforms, even in schools officially regarded as implementing them well, was qualified. This, of course, is entirely typical of ambitious and speculative reforms, and had been characteristic of earlier Malaysian reforms. Hence some elements of the official discourse of science education – such as constructivist teaching and mastery learning – had hardly entered practitioner thinking, and others – such as science process skills, thinking skills and metacognition – had entered to some degree but often in restricted range. However, against these familiar conservative trends, there was stronger adoption in the well-regarded Smart schools of two aspects of official recommendations – student-centred learning and using ICT resources. Not only had these aspects been given particular emphasis in the discourse of the Smart School reform; they had also received considerable material support through the Initiative's provision of technological infrastructure and curriculum-appropriate resources. Moreover, in the Smart schools these two aspects were strongly intertwined, vindicating – to a degree – the policy assumption that increasing deployment of digital technologies would play an important enabling function for the wider educational changes proposed for Smart schools – at least in the form of more student-centred learning. Moreover, against the trend of earlier research findings that have led to the viability of reform efforts of this type being questioned, forms of classroom practice have evolved in these schools in which technological and pedagogical development appear to be mutually supportive.

It was these intertwined aspects – student-centred learning and using ICT resources – which primarily characterised the *distinctiveness* of science teaching in the successfully-implementing Smart schools, compared to their neighbouring Mainstream schools. These differences were associated with overall trends that indicated the relative effectiveness of the Smart schools in promoting positive attitudes to science amongst students, in developing their science process skills, and in advancing their general science attainment. However, closer analysis identified a mediating effect of attainment on entry to secondary school. Whereas the attitude effect was present across student groups, the two academic effects were very much weaker for students who had been low-attaining when they began secondary education. We recommend further investigation of this apparently differential effectiveness of science teaching in Smart schools. One plausible line of enquiry would be through comparing the degree and forms of engagement of lower-attaining students (with their average- to high-attaining peers) in those forms of classroom practice which proved distinctive to science teaching in Smart schools.

Since the pilot phase of the Smart Schools Initiative ended in 2002, more Malaysian schools have been designated ‘Smart’. According to internal evaluation (Norrizan, 2007), many Smart schools have a questionable level of ICT usage in teaching and learning, and indeed in school management. With a view to supporting school development and clarifying evaluation standards, the Malaysian Ministry of Education has launched the Smart School Qualification Standards (SSQS) with a related Star Ranking (Malaysian Ministry of Education and Multimedia Development Corporation, 2007). SSQS provides a set of indicators to measure ICT utilisation and guidance, intended to help lower-ranking Smart schools monitor and improve on their ICT usage and enhance their quality of education. What our research contributes to this effort is an empirically-grounded analysis: first, of what successful development to date looks like at the classroom level in terms of the interplay between ICT resources and science teaching and learning processes; and second, of the ways in which such development is proving more and less effective for different attainment cohorts on entry to secondary school. Equally, however, we suspect that because this Malaysian situation has many commonalities with similar developments in other educational systems, this study has the potential to provide insights of wider interest and value.

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Table 1: Summary of salient episodes involving note giving and copying

School	**Teacher/Class/ [Lesson]**	**Time: Episodes**
MS1	AMS1/3A1/[1]	0818/0840: Ss copy cross sectional diagrams of, and related notes on, Hibiscus and *Semarak Api* from the OHTs.
	/[2]	0823/0845: Ss copy diagrams of, and notes on, self- and cross-pollination from the OHTs. 0845/0900: Ss copy notes on the advantages of cross-pollination and its applications in agriculture from the blackboard.
	AMS1/3A4/[1]	1047/1057: Ss copy answers to the workbook questions on parts and functions of male and female reproductive organs from the OHTs.
	/[2]	1025/1046: T orally provides answers to questions in workbook while Ss copy.
	BMS1/3A7/[1]	1124/1135: T dictates answers to workbook questions on “Growth from embryo to foetus” while Ss write. 1139/1155: Ss copy diagram on various stages of embryo and foetus from an OHT.
	/[2]	0825/0838: Ss copy notes on menstrual cycle from the OHTs.
MS2	CMS2/3A/[1]	1244/1247: T dictates key points on dispersal while Ss copy.
	/[2]	1140/1146: T draws and labels a dicotyledon and monocotyledon while Ss copy.
	CMS2/3C/[1]	1300/1310: T dictates main points on “growth rate” while Ss write.
	DMS2/3E/[1]	1202/1232: T writes and explains key points on pollination on the board while Ss copy.
	/[2]	0908/0930: T writes key points of 5 different types of vegetative reproduction while Ss copy.
SS1	ESS1/3T1/[1]	1201/1211: Ss copy a diagram on “sexual reproduction” from the blackboard.
	FSS1/3T3/	*None*
	ESS1/3T5/[1]	0829/0841: Ss copy the sperm and the ovum diagrams/figures from the textbook.
SS2	GSS2/3K1	*None*
	KSS2/3K3	*None*
	JSS2/3K5	*None*

Table 2: Summary of salient episodes involving using ICT resources

School	Teacher/Class/ [Lesson]	Time: Episode
MS1	AMS1/3A1	*None*
	AMS1/3A4	*None*
	BMS1/3A7	*None*
MS2	CMS2/3A	*None*
	CMS2/3C	*None*
	DMS2/3E	*None*
SS1	ESS1/3T1	*None*
	FSS1/3T3/[1]	1050/1056: T uses PowerPoint to present the differences between a sperm and an ovum, analysing analogies employed. 1110/1120: Ss explore downloaded CD-ROM to fill up the information-gap activity worksheet given in the form of graphic organiser for identifying similarities and differences.
	/[2]	0827/0831: T shows on screen, an advertisement of a type of high-calcium milk powder, and discusses “for whom, and why it is needed”. 0833/0910: Ss explore the CD-ROM on “menstrual cycle” and answer 16 electronically-posed questions.
	ESS1/3T5	*None*
SS2	GSS2/3K1/[1]	1301/1336: Ss explore the pre-loaded materials on “development of fruits and seeds in plants”. (One pair of students observed attempting a mind quiz; listening to a text and attempting questions on “fertilisation in plants”; and finally performing a virtual experiment).
	HSS2/3K3/[1]	0741/0821: Ss explore a variety of pre-loaded activities on “analysing the growth pattern in humans”. 0831/0844: T shows graphically on screen, the growth pattern between boys and girls using Excel. 0846/0852: Ss do online test.
	JSS2/3K5/[1]	1227/1319: Ss explore pre-loaded materials from the computer. 11 Ss work individually, 8 in pairs and 3 in trio. (Individual students observed selecting different learning activities on “reproduction”).
		1321/1327: Ss check their in-boxes and respond accordingly.

Table 3: Excerpt showing a low-achieving boy exploring an animation.

Time	Description of Events
1248	Boy answers a question posed. This question shows an animation to which he must identify the process. He clicks on *penempelan* (implantation) as the response. Feedback indicates 'correct'.
1250	The boy now clicks on hypertext *proses perkembangan embrio* (The process of embryo development). He explores the text and watches the animation on, among others, amniotic fluid, embryo, and placenta. For placenta, he looks at its microscopic view. He reads a warning, saying "Don't smoke, don't take alcohol. Be responsible for yourself and the foetus".
1256	The boy then views the animation on the growth of a foetus to a baby. There are accompanying notes/texts to the animation.
1258	The boy now looks at the growth from 36th week till birth. He focuses on the animation for (i) changes at cervix, and (ii) the delivery process.
1300	He views the complication at birth: bridged position. Then, he reads a statement that invokes the feelings of joy and thankfulness for a baby who is born to a married couple.
1301	He is at a screen which says he may click on any picture to review or to re-visit previous texts/animation.
1302	He answers Q1. [Got it right only at 3rd attempt].
1303	He answers Q2. This question requires him to identify the place in which (a) fertilisation occurs, (b) implantation happens,
1305	He tackles the "Summative Quiz". Here, he has to drag and place ovum, amnion, zygote, and embryo to their correct places within a female reproductive system.
1307	The boy gives a sigh of relief when he has correctly placed them.

Table 4: Summary of salient episodes involving extended support for learning

School	**Teacher/Class/ [Lesson]**	**Time: Episodes**
MS1	AMS1/3A1/[1]	0739/0740: T assigns Ss to gather information on cloned babies. 0744/0814: Ss investigate the structure of a flower in groups of 3-8 students.
	AMS1/3A4/[2]	1048/1053: T asks Ss to get brochures, or look up in books/magazines for information on AIDS.
	BMS1/3A7/[1]	*None*
MS2	CMS2/3A	*None*
	CMS2/3C	*None*
	DMS2/3E/[1]	1232/1232: T reminds Ss to find information on the benefits of self- and cross-pollinations.
SS1	ESS1/3T1	*None*
	FSS1/3T3/[1]	1046/1048: T encourages Ss to work in pairs at the computer terminals. 1110/1120: Ss explore downloaded CD-ROM to fill up the information-gap activity worksheet given in the form of graphic organiser for identifying similarities and differences.
	/[2]	0833/0910: Ss explore the CD-ROM on "menstrual cycle" and answer 16 electronically-posed questions.
	ESS1/3T5	*None*
SS2	GSS2/3K1/[1]	1301/1336: Ss explore the pre-loaded materials on "development of fruits and seeds in plants". (One pair of students observed attempting a mind quiz; listening to a text and attempting questions on "fertilisation in plants"; and finally performing a virtual experiment).
	/[2]	1308/1310: T forms expert groups on exosphere, ionosphere, stratosphere, troposphere, continental, and cyme. 1310/1327: Ss discuss in their respective expert groups. 1332/1358: Each group presents the key points of their discussion.
	HSS2/3K3/[1]	0741/0821: Ss explore a variety of pre-loaded activities on "analysing the growth pattern in humans".
	JSS2/3K5/[1]	1227/1319: Ss explore pre-loaded materials from the computer. 11 Ss work individually, 8 in pairs and 3 in trio. (Individual students observed selecting different learning activities on "reproduction").

Table 5: Differences in science attitude, process and attainment outcomes between Smart and Mainstream school-types

Student outcome	**Instrument Employed**	**Effect size (significance)**	**Entry-grade related exceptions**
Attitudes towards science	Malay version of Attitudes Towards Science in School Assessment [ATSSA] (Germann, 1988)	+0.68 ($p<0.001$)	
Science process skills	Malay version of Test of Integrated Process Skills II [TIPS-II] (Burns, Okey, and Wise,1985)	+0.37 ($p<0.001$)	Small effect size (+0.12) at grade D level
General science attainment	Science Lower Secondary Assessment within the Malaysian Standardised National Examination [SNE]	+0.41 ($p<0.001$)	Small effect size (+0.08) at grade D level

(+ effect indicates difference favouring Smart school-type)