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Teaching and learning in the new sciences: A case for interdisciplinary inquiry-based learning

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Abstract:
Scientific knowledge and understanding is rapidly expanding at an ever-increasing rate. The new concepts and technologies emerging are giving rise to new scientific meta-disciplines that integrate the traditional disciplines of biology, chemistry, physics and geology, together with educational, commercial, industrial and social applications. These new sciences include nanotechnology, biotechnology, bioinformatics, bioethics, aquaculture, forensic science and communication technologies. Given that scientific research output is emerging as multi-disciplinary, teaching traditional disciplines of science in isolation is an increasingly unrealistic representation of contemporary scientific research disciplines. In order to develop a sound knowledge and understanding of science in the traditional disciplines as well as a keen awareness of the rapidly emerging understandings of these new meta-disciplines, the science curriculum needs to include a focus on the new sciences and the pedagogies required for their teaching and learning. As much of the new knowledge in the new sciences can be produced, and successfully taught only via digital technologies and provides ideas for inquiry-based learning, there is ample material upon which to carry out multimedia-based inquiry projects. These views come from experience designing and delivering curriculum centred upon the new sciences in an ICT-rich school of the future. Curriculum in the new sciences was designed around fertile questions integrating traditional scientific disciplines into inquiry-based learning experiences and incorporating the use of ICTs for the teaching, visualisation and demonstrations of learning new and abstract concepts. The paper discusses this mounting theoretical paradigm drawing from particular new science curriculum examples.

Background: A paradigm shift

The latest Organisation for Economic Cooperation and Development international survey of the present state of science education indicates that current school science curricula are not only disconnected from cutting-edge science, but disciplinary-based with rigid boundaries and that teachers lack pedagogical content knowledge of the new concepts and technologies emerging from scientific research (Sgard, 2005). Together, these facts indicate students receive instruction that not only lacks currency in the world, but does not accurately reflect the current nature of scientific research and development. If there is to be a reform in science education to more accurately reflect the current research culture then there needs to be a greater focus on new fields of research

"A reinvention of science education calls for a recognition of the many changes in the social and economic characteristics, ethos, practice, and culture of science. For more than 350 years schools science curricula have been modelled on such disciplines as biology, chemistry, earth science and physics. These disciplines today have become split into hundreds of research fields" (Hurd, 2002, p5).

As new scientific information and technologies become known, new meta-disciplines are formed that integrate traditional disciplines of science with educational, commercial, industrial or social applications. These scientific meta-disciplines include among others, nanotechnology, biotechnology, bioinformatics, bioethics, aquaculture, forensic science and communication technologies.
As Schank and Wise (2006) advocate, teaching of cutting-edge science topics not only increases interest in science but develops a sound knowledge and understanding of science in the traditional disciplines with an awareness of how they are integrated to create new scientific concepts. "Cutting-edge science topics can engage students, reinforce core science concepts, and give students a better idea of how the traditional disciplines tie together" (Challenge 3: Preparing Teachers para 2). While the products of science remain important within these interdisciplinary cutting-edge sciences, the context is different. Rather than committing facts to memory and studying traditional science disciplines for their own sake, scientific concepts are implicitly integrated, and connected in a way that knowledge in one field is influencing and informing endeavours in another (i.e. interdisciplinary) (Southerland et al., 2003). For example, bioethics is the application of ethical decision-making paradigms, considering rules or principles (i.e. right vs wrong) that may be defined by the consequences of the application of a new scientific discovery or technology (Johansen and Harris, 2000). The knowledge of ethics can inform the management or use of a biotechnology (for example the Gene Technology Act 2000 of Australia that informs the regulation of genetically modified organisms). Another good example is the new field of nanotechnology which is described as the "physical, chemical, and biological principles that govern the behaviour of particles on the nanoscopic scale" (Schank et al. 2004). This new meta-discipline integrates scientific concepts from chemistry, physics, biology, engineering, technology and materials science (Wise et al., 2006). Biotechnology, simply defined as using living things to create products, brings together concepts from biology, chemistry, business and technology (medical, industrial and genetic). It is the practice of using organisms and biological processes to produce foodstuffs, medicines, diagnostic tests and waste removal mechanisms. Bioinformatics, also referred to as computational molecular biology or biocomputing, integrates information from biology, chemistry and computer science.

"Bioinformatics has evolved into a multidisciplinary subject that integrates developments in information and computer technology as applied to biotechnology and biological sciences. Bioinformatics uses computer software tools for database creation, data management, data warehousing, data mining and global communication networking. Bioinformatics is the recording, annotation, storage, analysis, and searching/retrieval of nucleic acid sequence (genes and RNAs), protein sequence and structural information" (Kumar, 2005, What is bioinformatics? para 1).

Aquaculture, also known as aquafarming, is "the science (biology and chemistry), art, and business of cultivating marine or freshwater food fish or shellfish, such as oysters, clams, salmon, and trout, under controlled conditions" (American Heritage Dictionary®, 2000). As these meta-disciplines all represent an integration of various science disciplines with other disciplines, they provide an organic interdisciplinary approach to the study of science in the classroom.

Disparity between the scientific world and the curriculum

Not only is cutting-edge science emerging as multidisciplinary, but scientific research is driven by questions (inquiries) that are often answered by the integration and understanding of various scientific disciplines. At times addressing research questions requires content knowledge of one scientific discipline and methodological or technological knowledge of other scientific and/or non-scientific disciplines. Although some scientific research rests within the confines of a scientific discipline, often, the research questions are driven by societal needs, commercial interests or advancement of basic knowledge requiring an awareness and knowledge base that rests outside of the scientific discipline boundaries. Peter Fensham (2004, chapter 10, p147), a science educator and scientific researcher highlights this issue. "The knowledge of biology or chemistry or physics has been developed in the contexts of inquiry and investigation." Fensham goes on to emphasise that although this is the reality of the scientific world, the curriculum does not reflect that reality, but instead focuses on discipline knowledge, often in isolation, rather than how it may integrate with other disciplines. "These contexts are quite different from the contexts of schooling, particularly schooling which has a more liberal or general purpose. In other words, the knowledge in these sciences is not automatically in a form that makes it meaningful or worthy."
The current state of science education is not only unrealistic and limiting, but may well contribute to the lack of interest in science that is a global phenomenon (Sgard, 2005). Moreover, if science curricula are going to emphasise the nature of science then the approach to teaching and learning will need to reflect how scientific knowledge is constructed, which is often not within the boundaries of a single discipline. Although "Most of the successful science learners in school master a lot of conceptual science content," they "have little sense of the nature of science itself" (Fensham, 2004, chapter 15, p205). There are several notions of what constitutes the nature of science in the literature (see Khishfe and Lederman, 2006) but there is consensus regarding certain characteristics. Khishfe and Lederman describe these commonly cited characteristics of the nature of science as epistemological (i.e. of the nature and foundation of knowledge) in that scientific knowledge can be constructed in a biased or subjective way, built empirically, socially and culturally influenced, produced through creativity and tentative (subject to change with emerging evidence). Other characteristics include the nature of and contrast between theories and laws. Although these characteristics are accurate, they lack an essential truth. Inquiry is the keystone of the nature of science; scientific research is driven by inquiry, the need to solve the unknown or answer unsolved problems or questions. The truth is that scientific research questions are often of the nature that they evolve and are answered only through multidisciplinary routes.

Regardless of whether or not students seek to pursue a science career pathway, the need to develop scientific literacy skills is important given the ubiquitous exposure to emerging social scientific issues and discoveries.

"The fact remains, nevertheless, that the socio-scientific situations and issues now confronting citizens are not confined within disciplinary boundaries. Citizens need to appreciate the relationships between knowledge in the sciences and other knowledge, as well as how the sciences coordinate their knowledge in application to these situations" (Fensham, 2004, chapter 10, p159).

Fensham stresses that this will require a different approach to the teaching of science, where education moves outside of individual scientific discipline boundaries. "Now that there is a heightened interest in scientific literacy as the major outcome of school science, the curriculum needs a broader knowledge base from which to draw its knowledge of worth than single disciplinary sciences can provide" (p158).

Implementing the Integrated Approach

There is a long history of debate over the costs and benefits of curricula that support teaching of discrete science disciplines and those that take a blended or integrated approach (see McComas and Wang, 1998; Meier et al. 1998; Rudolph, 2002). Those that support a blended instructional approach (see Meier et al., 1998) cite research reporting an increase in content knowledge and problem solving abilities (Goldberg and Wagreich, 1989; Shann, 1977) as well as scientific literacy skills (Friend, 1985) in students exposed to this educational strategy. Southerland, Gess-Newsome and Johnston (2003) cite barriers to the success of a blended science curriculum including teachers' lack of adequate breadth of content knowledge, the paucity of instructional models and materials, lack of time to plan, insufficient team teaching experience and lack of adequate administrative or financial support (Czernek, Weber, Sandmann, and Ahern, 1999; Mason, 1996). These barriers weigh heavily on the teachers' ability to develop the necessary pedagogical content knowledge (PCK) or the "knowledge base that influences teachers' approaches to, and practices of, teaching" (Loughran, Mulhal and Berry, 2004, p371). However, research reported by Loughran, Mulhal and Berry details the discovery of a novel way to convey science teachers' PCK as something that is not sufficiently expressed by an individual teacher but complementary aspects of PCK are holistically revealed with teams of teachers. Although this finding describes a pedagogical shift, it advocates team planning and teaching of curriculum highlighting scientific concepts that tie together multiple disciplines.

Another pedagogical shift implicit in teaching new science is the inherent requirement to use digital technologies (i.e. information and communication technologies or ICTs) to teach
new concepts. Digital representations modelling new scientific processes or phenomena (i.e. simulations) place special demands on teachers' pedagogical content knowledge of science. This new demand on teachers highlights a special relationship between developing ICTs and the pedagogical content knowledge of new science (La Velle, McFarlane and Brawn, 2003).

Science education can more accurately reflect the true state of the scientific research world by (1) incorporating into the curriculum the new scientific meta-disciplines and their social applications, (2) providing science instruction that demonstrates its relationship with other disciplines and (3) designing authentic learning experiences that reflect the true nature of inquiry in research (that to answer a research question requires the integration of science disciplines and their influence on or relationship with other disciplines). Practical examples of this educational approach will be discussed but not without foregrounding several assumptions: that sufficient time is allocated to plan, that a team of teachers with complementary skills and knowledge are chosen and provided with mentorship and professional development, that there is sufficient time and appropriate scheduling to implement the courses, and that both administrative and financial support is provided.

**BROAD INQUIRY - FERTILE QUESTION**

![Diagram](image)

- **ENGAGEMENT THROUGH IMMERSION ACTIVITIES**
- **EXPLORATION / INVESTIGATIONS / MINI INQUIRIES**
  - Topic 1
  - Topic 2
  - Topic 3
  - Topic 4
- **EXPLANATION/ELABORATION**
  - Response 1
  - Response 2
  - Response 3
  - Response 4
- **AUTHENTIC CULMINATING ASSESSMENT TASK**
  - EVALUATION THROUGH REFLECTION
  - RESPONSE TO FERTILE QUESTION

*Figure 1: An inquiry model for the teaching of a science unit.*

**Teaching and Learning New Sciences: One approach**

Figure 1 provides a diagrammatic depiction of the proposed educational strategy showing the structure of the courses which are referred to as 'central studies units'. Each unit of work is framed as a broad inquiry driven by a fertile question. The planning team chooses this question with the notion that it is positive, provocative and conducive to a constructivist learning environment. Students are made aware of the fertile question at the start of every unit. The unit is structured as parallel smaller inquiries or investigations within a broad inquiry prefaced by a number of engaging activities to immerse students into the inquiry topic and culminating into a final assessment that encourages metacognition and evaluation of the smaller inquiries in order to respond to the fertile question. Although the broad inquiry is not open-ended, that is the students don’t create their own broad inquiry (i.e. choose the question), the smaller inquiries provide an opportunity for students to design a question to study, guided, and within the framework of the topic. The smaller inquiries or investigations (or choices therein) are designed with the intention to allow students to construct deep
understandings of the science disciplines underpinning the various topics to address the fertile question and with the insight that several opportunities be provided to make connections between concepts, contexts and disciplines (science and non-science). The smaller inquiries or investigations require responses in the form of assessment tasks that provide opportunities for diverse demonstrations of learning. The culminating assessment task allows students to reflect and evaluate on their learning through the smaller inquiries and investigations in order to respond to the fertile question.

**BROAD INQUIRY – Who wins in Biotechnology?**

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**AUTHENTIC CULMINATING ASSESSMENT TASK: COLLABORATIVE GROUP RESPONSE TO:**

Who wins in Biotechnology?

*Figure 2: An inquiry model for the teaching of a Biotechnology unit.*

An authentic example of a central studies unit is provided in figure 2. This unit has been carried out with year ten and eleven composite classes. The fertile question driving the broad inquiry is “Who wins in Biotechnology?” Many biotechnologies, although produced for the benefit of society, have been mired in controversy over their potential adverse applications or effects on humans. A great example is the risk assessments that have been done on genetically engineered foodstuffs. As biotechnology brings together biology, chemistry, technology and business and is frequently evaluated using bioethics, this unit was designed to reflect these current realities. Moreover, to respond to the fertile question, the construction of an understanding of specific concepts that tie these disciplines together is necessary. The immersion activities were run over the first two weeks of the unit and included group definitions of biotechnology, shopping for biotechnology foodstuffs (food products that require biotechnology to create them), discussing case studies pertaining to various biotechnologies and extracting DNA from a variety of sources. Four separate inquiry or investigation topics followed the immersion activities including: (1) Old biotechnology (including a choice of investigating wine, bread or yoghurt making), (2) New biotechnology (involving both theoretical and experimental investigations of genetic engineering), (3) Evaluation of an Australian biotechnology company (entailing a scientific and business assessment of a chosen biotechnology company), and (4) Social issues (pertaining to an
analysis of socio-scientific issues related to biotechnology). The responses to these topics of inquiry or investigation included: (1) a small grant application for funds to carry out experimentation on a choice of old biotechnologies and a digital recording of the investigations and conclusions (2) a practical report on bacterial transformation and subsequent (newly expressed) protein isolation. (3) the design of a new company web-site including all relevant scientific and business information and (4) a social issues report on evaluation of a chosen biotechnology issue. Within these smaller inquiries, there was the inclusion of explicit teaching (i.e. explanations and elaborations) in discipline areas (e.g. chemistry of fermentation, biology of transcription and translation) that supported the construction of deep understandings of biotechnology. The culminating assessment task required students to provide a written response to the question “Who wins in Biotechnology?” through a collaborative group task.

Figure 3: A diagrammatic depiction using a puzzle to show how teaching new science brings together the essential elements to create science education that reflects the true nature of scientific research.

Teaching new science with this approach portrays the true nature of the scientific research world as it facilitates: (1) the application of the inquiry process in scientific research, (2) an understanding of the true nature of science, (3) the integration of science disciplines (within emerging scientific concepts) and (4) the building of pedagogical content knowledge through a team of teachers with complementary discipline expertise. An additional component of the PCK element that is essential to teaching and learning of new sciences is the use of digital technologies for explicit teaching of new scientific concepts that models and encourages digital scientific communication or demonstrations of understanding by students. Figure 3 demonstrates how these elements, the pieces of the puzzle, are pulled together by the teaching of cutting-edge science.

This paper discusses a paradigm shift not only in science education but in how we think about the PCK of science, the nature of science, the inquiry process and school organisational structure. Updating of traditional science discipline subject matter and curricula, as has been the example of reform in science education’s history, is insufficient to meet the changing nature of scientific fields of research. With the continuing emergence of new scientific meta-
disciplines the current modes of educational practice (including inquiry approaches) need to be updated.

References: