Encyclopedia of Science Education

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With 88 Figures and 32 Tables

Springer Reference

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Preface

This is the first English language Encyclopedia of Science Education to be published and, as far as I have been able to determine, the first Encyclopedia of Science Education in any language.

But "being the first" does not mean "this is needed." So why an *Encyclopedia* of Science Education? This was literally my immediate reaction when Harmen van Paradijs, then Springer's science education editor, first asked me some years ago if I would create and edit an Encyclopedia of Science Education for Springer. After all, quite comprehensive handbooks of Science Education had been a common feature of our research world for two decades: The USA-based National Association for Research in Science Teaching (NARST) initiated the first (in 1993, edited by Dorothy Gabel). At the time Harmen spoke with me, there were two current well-known handbooks, one endorsed by NARST (edited by Sandra Abell and Norman Lederman) and the other published by Kluwer (now Springer, edited by Barry Fraser and Kenneth Tobin), and the second (and current) editions of each of these were both already well underway. Two of the eventual seven volumes in the regionally focused series of handbooks of Science Education research published by Sense had by then been completed. And the journal *Studies in Science Education*, a journal primarily devoted to reviews of science education research, was then in its 45th year. Clearly, an encyclopedia was not justified if it was to be just another form of handbook.

Why *This* Encyclopedia of Science Education?

In general terms, an encyclopedia ought to be different from a handbook, given both the format of large numbers of separate contributions ordered alphabetically (rather than single-/joint-authored major reviews of broad topics) and the ways this differing format invites different approaches to synthesizing research findings and future directions.

I spent some time considering the question of why *this* Encyclopedia of Science Education before deciding I had answers acceptable to me and so agreed to Harmen's invitation. Arriving at my answers involved exploring two things: whether I believed science education warranted an encyclopedia and how such a publication could be sufficiently different to anything currently in existence so as to attract me to accepting the major commitment that the creation and editing would involve.

Commonly, encyclopedias are defined as something of the form of "a comprehensive reference work – book or set of books – containing extensive information on all branches of knowledge or on one particular branch of knowledge, usually arranged alphabetically." The issue as to whether or not science education deserves such a publication is, as I see it, easily settled. As an English language label to describe an area of research and teaching, "Science Education" essentially emerged for the first time in the very early 1960s. This was in particular response to the proliferation of a range of evaluation types of studies of the then new and large-scale US science curriculum projects. It was at this time, for example, that the first named Professors of Science Education were appointed (first in USA, then in Australia). Thus, the discipline is, by this name, only about half a century old. Yet, science education has developed rapidly and remarkably. Fensham's 2004 book *Defining an Identity: Science Education as a Field of Research* (Kluwer) alone would make a convincing case in the powerful presentation of data and analyses that he gives to support the proposition that science education does indeed have the status of a distinct "field of research." Many other observations are also convincing about this status of science education; for example, there are now at least eight specifically science education journals included in the highly selective Thomson Reuters (formerly ISI) Web of Knowledge database and several others such as *Science Communication* and *Science and Society*, in which science education researchers are among those who publish. This is considerably more than for any other specialist school curriculum area.

So I became comfortable with the notion that science education as a research field warranted an encyclopedia. And then, I saw that something of substantial potential worth and quite different to what currently existed could be attempted – in short, I would attempt to have research authors and research traditions from beyond the dominating anglophone/English language research world represented in the encyclopedia. That is, I would take "comprehensive," perhaps the central characteristic of an encyclopedia, to include recruiting authors from around the globe and attempting to identify and include relevant non-English language constructs and literatures and perspectives – while being clear at all times that this was to be a solely English language publication.

Some researchers have previously pointed to the sharp contrast between the nature of causality that science itself seeks and the nature of causality that it is feasible to seek in science education. In simple terms, causality in science seeks to be singular and absolute, while causality in science education is necessarily multiple and relative (e.g., both *context* – including the content that is the focus of the teaching/learning/curriculum/assessment – and *time* are very often determining causal variables in our research even though they are often treated as issues that can somehow be ignored or "controlled"). Too often, science education research and practice seeks some form of absolute and constant causality that cannot be attained.

One central aspect of the multiple causality that is inherent to [science] education research is that some fundamental issues are conceptualised quite differently in different sociohistorical-cultural contexts. That is, for some issues, the beginning points of even thinking about how to investigate aspects of causality are in sociohistorical-cultural contexts different to, for example, my own. A quite widely recognised example of this, an example that is also frequently only understood at the most superficial level in the anglophone world, is the way in which the range of issues the anglophone world gathers together under the broad concern of "how do we decide what content to teach and how to teach this?" are conceptualised in parts of continental Europe (see the entries *Bildung* and *Didaktik* in this encyclopedia). The issue I saw as "being of substantial potential worth and quite different to what currently existed" that I have attempted to include in this encyclopedia is that of alternative ways of conceptualising central issues in science education that, for those of us who are monolingual, are currently unavailable.

The Processes of Generating the [Changing] List of Entries

I first began by recruiting a number of outstanding science education scholars to work with me as an Editorial Board, with each of them having particular expertise in one of a range of broad areas (Assessment, Curriculum, Nature of Science, Teaching, Learning, etc.). All are from the anglophone world of science education research – I had a further strategy to broaden the range of entries and authors (see below).

The Editorial Board had one face-to-face meeting immediately prior to the 2010 conference of the National Association for Research in Science Teaching. This was supported by Springer with costs and with both secretarial and intellectual support. Prior to that meeting, I generated a first draft of possible entries by (a) using the indexes of the two Handbooks of Science Education that were in print then and (b) working through the complete contents to that time of the review journal *Studies in Science Education*. We (the Editorial Board) then spent most of our one meeting working through this list, revising and adding and deleting entries and sometimes suggesting authors. We also agreed on the ways we would divide up the work involved in seeking authors and editing entries. Although it was never intended that the final publication would involve separate sections, the allocation of responsibilities by section was to enable the best use of the outstanding expertise involved on the Editorial Board.

Entries relating to Assessment and Evaluation were the responsibility of Audrey Champagne, Curriculum – Robin Millar, Intersections with Other Substantive Areas – Justin Dillon (resigned March 2011; I took over these entries), Learning – the late Phil Scott and me (because of the extremely large number of entries here, Phil and I intended to share responsibility; on Phil's tragically early death in July 2011, I took over all entries in this area), Nature of Science – Rick Duschl; Science Education in Out-of-School Contexts – Léonie Rennie, Socio-Cultural Dimensions of Science Education – Bill Cobern, Teacher Education/Teacher Development – John Loughran, Teaching – John Wallace, Technology-Enhanced Learning – Doris Jorde, replaced by Jim Slotta in January 2012.

Over the next several months, the list of proposed entries was further developed and expanded to include notional length (either short [up to ~1,000 words], medium [~1,200–1,500], long [~1,500–4,000] or essay [~5,000]) and an outline of a sentence or two about the intent of the entry. These two added features were to enable invited authors to be more informed about the task. The list of entries has remained a changing phenomenon right to the point of production. I am very grateful to all members of the Editorial Board for the wholehearted and insightful ways they engaged with this uncertain process of developing what the encyclopedia would contain and for which we were continuously working out for ourselves how to approach this central task.

Our approaches to expanding the entries and authors to embrace ideas and people from beyond the anglophone world involved my creation of an Advisory Board of science education academics. These were scholars who knew well the English language literature in their specialty, who knew well the literature in their first language, and who knew the ways research was conceptualised in their own culture. The invitations I sent out early in 2011 explained the embracing of ideas and people beyond the anglophone world I wanted to include in the encyclopedia. I included the list of entries as it then stood and described what I was inviting them to undertake as considering the list of proposed encyclopedia entries with the task of identifying

(i) Potential authors from beyond anglophone contexts for entries proposed by the Editorial Board.
(ii) Issues (potential entries) that do not appear in this list of entries generated by the Editorial Board that are of importance to the traditions/literatures with which the Advisory Board member is familiar.
(iii) Entries that are on the list for which the perspectives of the Advisory Board member's tradition/literature are different from the perspectives of the anglophone traditions and literatures and different in significant ways – that is, in ways whose elaboration will help inform and enhance the English language/anglophone perspectives.

Those who agreed to be involved and their countries are Jens Dolin (Denmark), Reinders Duit (Germany), Mansoor Niaz (Venezuela), Masakata Ogawa (Japan), Roser Pintó (Spain), Marissa Rollnick (South Africa), Jinwoon Song (Republic of Korea), Fatih Taşar (Turkey), Andrée Tiberghien (France), Benny Yung (Hong Kong SAR, People's Republic of China).

As with the Editorial Board, I am extremely grateful for the considerable time and expertise that these members of the Advisory Board have given to the production of the encyclopedia.

The Nature of the Final Entries

In this first edition of the Encyclopedia of Science Education, there are 383 substantive entries and another 1793 entries that are only cross-references (e.g., there is an entry *Accommodation in Piagetian Theory* that is only a cross-reference – see “Piagetian Theory” – because Accommodation as advanced by Piaget is discussed in detail in *Piagetian Theory*). These entries have involved 353 different authors, and the authors plus Advisory Board members plus Editorial Board members have come from 36 different countries.

Some entries are of considerable length and cover all of a major field (e.g., *Piagetian Theory*), and others, by the specific circumstance of related entries, are quite brief (e.g., *Meaningful learning* is only about 140 words because this construct and the way it has been conceptualised in science education is considered at some length in the entry *Ausubelian Theory of Learning*; therefore, *Meaningful learning* is cross-referenced to *Ausubelian Theory of Learning* rather than all relevant material being repeated in each entry).

The intended audience for this encyclopedia is, put simply, beginning researchers – either research students (and so “beginning” in the conventional sense) or existing researchers who are exploring an area beyond their current expertise (and so “beginning” only in terms of the focus of the entry they seek). Clearly then, the expectation of all involved in the production of these volumes is that readers will always be sampling the specific parts that reflect their needs at the time and following cross-references as appropriate to further explore their immediate needs. It is very hard to imagine this work being read in the sequential manner of conventional books.

Acknowledgements

It is appropriate for me to repeat here what is written above – both the Editorial Board and the Advisory Board have given a very great deal by way of commitment and expertise to the production of this encyclopedia.

While all members of both Boards have been absolutely central to the development of this encyclopedia, I have used two members of the Editorial Board more than all others as sources of advice and as sounding boards for my thinking – my two Australian friends and colleagues Léonie Rennie and John Loughran. I am especially grateful to them for their unfailing and immediate willingness to help in a variety of ways and with a huge range of thoughts and concerns. John also has my sincere thanks for the ways he has happily and very helpfully responded to my innumerable verbal queries delivered (usually) very early in the morning as he sat in his Dean’s office trying to do uninterrupted work only to have me rush in and ask about my latest encyclopedia concern.

I also wish to specifically acknowledge the contributions of the late Phil Scott. Phil and I had been colleagues and friends since his first year at the University of Leeds (which coincided with a period of sabbatical leave I spent at Leeds). Initially, as he and I worked together on the development of entries related to Learning, I could not have asked for a more expert and congenial colleague – just as Phil was, unfailingly, with all. Then, after his sudden death, I invited those authors he had suggested in ways that made it clear that the suggestion of the author was Phil’s, not mine. The response was almost

ubiquitously remarkable. It was not that people said “yes” (as they almost always did); it was that they were genuinely touched by it being Phil’s idea to involve them. The warmth felt towards this wonderful man shone through over and over again.

Melbourne Richard Gunstone
Jan 2014

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[1]Resigned March 2011
[2]Resigned January 2012
[3]Died suddenly July 2011
[4]From February 2012

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Hidden Curriculum

► Companion Meanings
► Curriculum

High Stakes Testing

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Keywords

Standardized achievement tests

"High stakes tests" are so labeled because they carry serious consequences for the students and/or educators. They normally take the form of standardized achievement tests and are common tests across a nation, state, or city. The results of the tests impact on students in terms of whether they get a special diploma or certificate for gaining entrance to a higher level of education. There is impact on schools or teachers or educators including financial rewards, funding level provisions, public perceptions, social status, or even sanctions.

As the consequences are serious, parents, students, educators, and the public in general have concerns about these tests, including validity issues and unintended negative consequences. Some researchers are of the view that it will require further studies to establish the positive impact of these tests. They maintain that there is a lack of evidence to show that testing improves student learning or instruction. There are financial implications for the design and administration of the tests. Some educators are concerned about teaching to the test, as less emphasis may be placed on concepts or content which are not tested.

Despite the serious consequences, there are researchers who advocate for the positive impact of high stakes testing. They maintain that students become more motivated or work harder and parents become more involved. There are suggestions that high stakes testing provides fair judgement for progression to higher education. Good scores further motivate student learning, while teachers provide better instruction to students and are motivated to figure out ways to improve student learning outcomes.

There are suggestions to provide alternatives to the large-scale testing approach, e.g., adoption of school-based assessment. These practices have led to discussion and research on teacher judgement. Furthermore, there is research which looks into the impact of high stakes testing on ethnic minorities and ELLs.

Cross-References

► Alignment
► Assessment: An Overview
► Assessment: PISA Science
► Assessment to Inform Science Education

History of Science

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Case studies; History; Interdisciplinarity; Kuhn; Nature of science; Philosophy of science

History of science is one of the reference disciplines in science education research and practice. Science education and the history of science have a long record of interactions, based on the role that history has consistently played in the narratives of science and its teaching. But, in addition, they have lived convergent developments in their making as modern academic disciplines from the

1960s to the present. A good illustration of this special relationship is the large impact that, in the last half century, Thomas S. Kuhn's *The Structure of Scientific Revolutions* has had on both fields. But the lives of history of science within science education are not restricted by the Kuhnian framework. The integration of history of science in science education has been shaped by a wide range of approaches and intellectual traditions. The development of history of science and science education as independent academic disciplines has also contributed to their estrangement, in spite of preserving a fertile common ground for cooperative assessments of the nature of science and its practice.

The history of science has been used as a tool in science education with the aim of providing an accurate view of how science works, a better understanding of scientific concepts and ways of knowing, and a contextual account of the place of science in human culture and society. It contributes to enhance motivation among students with regard to subjects often considered difficult, to provide a sweeping picture of science as culture, and to encourage informed participation in science and technology debates in the context of active citizenship. History of science is able to provide teachers and students with a wider and deeper understanding of science and the natural world. In addition to these large aims, history of science is a strategic resource for the production of pedagogical tools aimed at developing specific educational goals. It has intervened, for instance, in the study of conceptual change, the improvement of scientific literacy, and the dissection of the process of scientific discovery, theory building and experimental evidence uses. Pedagogical actions have made use of elements such as the replication of historical experiments, the use of classic science texts, the analysis of science rhetoric and syntax, and the building of pedagogical narratives by means of biography and key conceptual and experimental developments in historical perspective.

Putting history of science to work in science education is an acknowledgement of the fact that "history" and "science" are not mutually exclusive at all. Past events in science can be productively used to reflect on current problems. Whether leading to standard knowledge still in use, or to knowledge discarded in contemporary views, the past obviously offers the benefit of hindsight. Furthermore, the writing of science's past is supported by a mature discipline, history of science, characterized by a healthy pluralism and constructive criticism, thus able to offer penetrating insights on the making of science.

By engaging with history of science, students can reenact science in the making, according to past experiences, to confront analogous practical and intellectual problems and to deal with comparable debates to those prompted by the original events. Students can gain thus a deeper understanding of the nature and practice of science and in parallel develop their own knowledge and competence. Moreover, research in science education has proved that, in spite of their obsolescence (by current science standards), the conceptual frameworks of past science are useful to reflect on the preconceptions held by current students and the pedagogical processes required to further the learning of new knowledge through conceptual change. Thus, a connection is established between the nature and acquisition of scientific knowledge, past and present, which is of great methodological use in the creation of pedagogical knowledge.

The creation and implementation of this knowledge in the classroom requires a number of techniques of intellectual abstraction and communication which involve turning to several bodies of disciplinary knowledge, including not only the history of science but also pedagogy, psychology, philosophy of science, sociology of scientific knowledge, and science and technology studies. Indeed, the use of history in science education comes usually in the form of integrated history and philosophy of science and case studies. This approach is a reflection of the early development of science education research and history of science as modern academic disciplines in the 1960s. But, in addition, it is a testimony to the pluralism of science education as a research subject.

Like philosophers of science, in the last half century, science education scholars have made a good use of history of science to develop case studies, with the aim of gaining a better understanding of the nature of science and implementing it in the classroom. However, as for historically minded philosophy of science, the use of history of science in science education is not a simple matter of applying knowledge coming from a different field. Instead, it requires a cooperative process of appropriation and integration which involves most reference disciplines within science education.

Aligning history of science with science education requires focusing on specific aspects of science in historical perspective which are potentially useful to confront special problems identified by educationists in contemporary teaching and learning of science. Furthermore, it requires operating under a solid and explicit educational theory, including a coherent integration of pedagogical, philosophical, and psychological elements, among others. The construction of such theory and the integration of history of science within it is obviously a complex endeavor, which often involves tensions between the different disciplinary frameworks involved. The successful resolution of these tensions requires transformation as a new field of knowledge is formed.

The difficulties of such enterprise have partly hindered a larger success of history of science within science education. While history of science occupies a traditional place within science teaching, as a way of humanizing science and illustrating its cultural status, its use as a powerful tool in science education research and practice is less common. Further obstacles arise from the difficulty of providing teachers and educationists with adequate training in an additional discipline, the complexity acquired by history of science as it has developed into a well-established discipline, and the increasing distance that separates historians of science and science education scholars as the two communities have built their own academic niches.

Nonetheless, there is an important community of scholars who have developed during the last half century major work which successfully integrates history of science in science education, and there are important scholarly frameworks for the development of team work aligning science education scholars and historians of science in the production of educational research and pedagogical materials.

Early examples of such initiatives include the *History of Science Cases for High Schools* developed in the 1960s by Leonard E. Klopfer and his collaborators on the model of James B. Conant's *Harvard Case Histories in Experimental Science*; the *Harvard Project Physics* ran between the 1960s and early 1970s by Gerald Holton, F. James Rutherford, and Fletcher G. Watson; and Stephen G. Brush's initiatives in the 1970s and 1980s, leading to contributions such as his *Resources for the History of Physics* and a revised edition of Holton's *Introduction to Concepts and Theories in Physical Science*. Since then, a large number of educational projects have incorporated history of science as a driving agent in their design. It would be impossible to cite all of them, but representative examples are the *Minnesota Case Study Collection* directed by Douglas Allchin; *Mindworks: Making Scientific Concepts Come Alive*, led by Barbara Becker; the *Pavia Physics Project*, coordinated by Favio Bevilacqua; *Project 2061* of the American Association for the Advancement of Science; and the European History and Philosophy in Science Teaching (HIPTS) project. The integration of history and philosophy of science in science education is the driving force behind the International History, Philosophy and Science Teaching Group, established in the late 1980s, and its flagship journal *Science & Education*.

The status of history of science in science education research and practice rests on a solid foundation. However, its consolidation will depend, first, on the production of further studies demonstrating that history of science contributes to significant improvement and increased efficiency in science education and, second, on the willingness of historians of science and science education scholars to cooperate and to fight against the effects of academic fragmentation, caused by disciplinary specialization. This effort could involve, on the one hand, the establishment of more ambitious and updated training schemes in history of science within science education programs, taking into account the major changes that have shaped this discipline in the last decade. On the other hand, it would require a greater acknowledgement by historians of science of the central role that educational research can play in the intellectual and academic development of their own subject and the availability of a large body of expertise in this field in their neighboring faculty of education. Misconceptions on the nature of education and on the nature of history are still frequent on both sides of the divide, but they could be fruitfully overcome with the strengthening and expansion of interdisciplinary programs of intellectual and educational cooperation.

Cross-References

▶ Biology, Philosophy of
▶ Chemistry, Philosophy of
▶ Context of Discovery and Context of Justification
▶ Earth Science, Philosophy of
▶ Empiricism

References

Duschl R (2005) Relating history of science to learning and teaching science: using and abusing. In: Flick L, Lederman N (eds) Scientific inquiry and nature of science: implications for teaching, learning and teacher education. Kluwer Academic Press, Dordrecht, pp 319–330

Hodson D (2008) Towards scientific literacy: a teacher's guide to the history, philosophy and sociology of science. Sense Publishers, Rotterdam

Kipnis N (1996) The 'historical-investigative' approach to teaching science. Science Education 5:277–292

Matthews MR (1994) Science teaching: the role of history and philosophy of science. Routledge, New York

Olesko K (2006) Science pedagogy as a category of historical analysis: past, present, and future. Science Education 15:863–880

History of Science in the Curriculum

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In the middle of the nineteenth century, the Duke of Argyll, in his presidential address to the British Association for the Advancement of Science, stated that "what we want in the teaching of the young, is, not so much mere results, as the *methods* and above all, the *history* of science." The Duke's exhortation has been more ignored than followed, but there has been a minority tradition in the US, UK, and European science education that has attempted to bring history into science curricula and classrooms. This minority tradition has been energized over the past decade by widespread inclusion of "Nature of Science" goals into national and state curriculum documents and science education standards; the argument of many is that the nature of science cannot be understood apart from its history.

At different times and places, there have been appeals to the following seven reasons for including a historical component in science programs (Matthews 1994):

1. History promotes the better comprehension of scientific concepts and methods.
2. Historical approaches connect the development of individual thinking with the development of scientific ideas.
3. History of science is intrinsically worthwhile. Important episodes in the history of science and culture – the Scientific Revolution, Darwinism, discovery of penicillin, and so on – should be familiar to all students.
4. History is necessary to understand the nature of science.
5. History counteracts the scientism and dogmatism that are commonly found in science texts and classes.
6. History, by examining the life and times of individual scientists, humanizes the subject matter of science, making it less abstract and more engaging for students.