VISUALIZATION IN MATHEMATICS, READING AND SCIENCE EDUCATION

Models and Modeling in Science Education

Volume 5

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ISBN 978-90-481-8815-4 e-ISBN 978-90-481-8816-1
DOI 10.1007/978-90-481-8816-1
Springer Dordrecht Heidelberg London New York

Library of Congress Control Number: 2010931653

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Preface

Science education at school level worldwide faces three perennial problems that have become more pressing of late. These are to a considerable extent interwoven with concerns about the entire school curriculum and its reception by students.

The first problem is the increasing intellectual isolation of science from the other subjects in the school curriculum. Science is too often still taught didactically as a collection of pre-determined truths about which there can be no dispute. As a consequence, many students do not feel any "ownership" of these ideas. Most other school subjects do somewhat better in these regards. For example, in language classes, students suggest different interpretations of a text and then debate the relative merits of the cases being put forward. Moreover, ideas that are of use in science are presented to students elsewhere and then re-taught, often using different terminology, in science. For example, algebra is taught in terms of "*x*, *y*, *z*" in mathematics classes, but students are later unable to see the relevance of that to the meaning of the universal gas laws in physics, where "*p*, *v*, *t*" are used. The result is that students are confused and too often alienated, leading to their failure to achieve that "extraction of an education from a scheme of instruction" which Jerome Bruner thought so highly desirable.

The second of these is how to accommodate a "science education for citizenship", one that is relevant to the needs of all students, in a curriculum which has traditionally been focused on the purpose (albeit usually distorted) of "science education as a preparation to be a scientist/engineer". While there are commonalities between the two, there will be differences between what is taught, how it is taught, and why it is taught. Teachers need a justifiable basis on which to distinguish between the two treatments of science.

The third of these is a consequence of the exponentially increasing gap between the phenomena in which science is currently interested and what science education seems able to address. The inability of planners to agree to a rolling evolution of the content taught has led to a curriculum which is, to a substantial degree, permanently overloaded and out of date. While science faces the modern world, science education seems too concerned with the challenges of yesteryear.

If science education is to seem important and relevant to young people, then it must be based, to a far greater degree than at present, on concepts that transcend sets of allied phenomena and to a lesser degree on concepts that are tied to specific facts. The current emphasis on "nature of science" is an honest attempt to do so. One major problem with this approach is the lack of a concise definition of "nature of science"—there is no such thing as "*the* nature of science"—which arises from the fact that science is a collection of tools that are applicable to a huge diversity of phenomena, from the study of viruses to the study of galaxies. A second major problem is that the resources available to, as well as the social conditions of, scientific enquiry are very different from those of school science education. As attempts continue to be made to evolve authentic approaches to the conduct of scientific enquiry in schools, a worthwhile step forward is to focus on the intellectual skills that would be an integral part of all such approaches. Of these, learning how to produce and use models, the theme of this book series, has a very strong claim for attention in that it includes skills that are vital not only in science but also in other core subjects, such as reading/language and mathematics.

Modelling is the mental production and subsequent display to others of a simplified representation of an object, idea, system, event, process, initially produced for a particular purpose. That purpose is to provide an explanation, whether of physical constitution, behaviour, or causality, or better still all three, of a phenomenon. While models, the outcomes of modelling, ultimately reside in the mind, they can be shared with other people in some or all of gestural, material/concrete, visual, verbal, and mathematical forms. The key element in modelling is *visualization* which is often taken to mean either the formation of a mental image or the presentation of that image in the world-as-experienced; however, many other associated interpretations are to be found in the literature.

In "*Visualization in Mathematics, Reading and Science Education*", Linda M. Phillips, Stephen P. Norris, and John S. Macnab have brought together and critically reviewed the research literature on the psychology of visualization as well as its relevance to and manifestation in the teaching and learning of the three school subject areas. It is perhaps a consequence of the range of definitions for "visualization" in use that firm conclusions are difficult to arrive at. The situation might be summarized as follows: the science education community is convinced on the value of visualizations in teaching and learning, the language education community believing it to be useful for particular purposes, while the mathematics education community is not at all sure about its place and value. However, the current strong interest in research about visualization could, it is to be hoped, lead to firmer conclusions.

Such a resolution could provide the basis of an address to the three challenges faced by science education and outlined above. In respect to intellectual isolation, mathematical modelling techniques (usually in the form of equations and graphs) are an invaluable approach to scientific modelling. If such techniques, with their inbuilt use of visualization, were systematically taught in mathematics education, then their transfer into and use by science education should be eased. As regards didactic teaching, the widespread use of visualization in the teaching of the interpretation of written texts could be translated into science education, with beneficial outcomes. "Science education for citizenship" should include an introduction to the use and interpretation of that set of visualizations—here meaning diagrams and the like—in common cultural use yet which have their origins in science. That set of representations will form a major part in the public presentations of topical scientific ideas, the former thus enabling easier access to the latter.

Switching the focus on visualization from science education in the foreground to the background, considerable benefits can be seen for both reading education and mathematics education. These form one clear argument: science provides a body of phenomena, facts, and ideas that can be visualized through both reading and mathematical representations. The bringing together of these three educational areas under the umbrella of visualization should enable students to become better educated and not merely instructed in separate subjects. Phillips, Norris, and Macnab are thus very appropriately placed within the "Models and Modelling in Science Education" series.

London, UK John K. Gilbert

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Overview

This time is both exciting and controversial for research on visualization. It is exciting because computers have made it possible for graphics, images, illustrations, animations, and virtual reality to reach new heights in colour, realism, interactivity, appeal, and complexity. Many producers of visualization media simply assume that visualization makes learning easier. In fact, some advocates imply that visualizations are the best way to learn. It is a controversial time because the evidence is sometimes equivocal and frequently unclear on whether these new heights achieved through powerful computers actually enhance learning. Nonetheless, the increased use of technology and the visualizations it can make available for teaching and learning cannot be ignored.

This book is about the history of visualizations dating back to the 1880s, the evolution of the concept since the first studies were conducted in the early 1960s, and a comprehensive analysis and synthesis of empirical studies across the disciplines of mathematics, reading, and science education. The questions of whether there is a defensible model of visualization and whether the use of visualizations has pedagogical merit are raised and discussed. Comments, recommendations, and suggestions for future research are proposed.

There is a dearth of research and scholarship on visualizations. The total number of empirical research articles we identified in mathematics, reading, and science education on the topic of visualization for the last 50 years is approximately 250, which is remarkably low when placed in the context of all the journal articles published across these three subject areas during the same period of time, which number in the thousands. One important conclusion of this book is that there are a number of important open questions with regard to the development and utilization of visualization objects and activities in education that warrant further empirical study.

A recent Google™ search on "visualization and education" yielded about 800,000 results. Given the comparatively small number of empirical articles in the area, this is a remarkable number. Whatever visualization in education is believed to be and whatever the evidence is for its efficacy, a lot of people are taking note of it. A number of distinct ideas seem to be rolled into the current discourse on visualization. One common usage involves the idea that visualization is something that people do—they visualize. This process is typically seen as a mental process in which certain thoughts have content that is related to—perhaps is identical to—the content of something that is seen with the eyes. A second sense of the term visualization refers simply to imagining: “Visualize yourself as financially successful”, perhaps. In another common usage, computer-generated animations are referred to as visualizations. Such animations might attempt to depict the motion of the molecules of a gas or the orbits of planets.

In all three senses of visualization mentioned in the previous paragraph, there is a common thread: visualization is considered to be educationally useful. Visualizations are touted, sometimes unreflectively, as aids to learning and understanding. This book contains a critical evaluation of the educational worth of visualizations. Five questions are answered:

1. How is visualization defined in the literature?
2. What constitutes a good visualization and what is necessary for individuals to interpret and evaluate them?
3. Do visualizations aid the development of reading ability, and, if so, how?
4. Do visualizations aid in the development of mathematical and scientific concepts, and, if so, how? and
5. How is computer technology affecting the development and use of visualizations?

The book is structured into three parts. Part I provides an introduction to the idea of visualizations: first, a commonsense view of visualization; second, a more precise examination of the meanings of visualization and the characteristics of good visualizations as found in the research literature; and, third, a look at three cognitive theories of the mechanisms of visualization and recommendations for the design of effective visualizations based on the theories. Part II examines the research on the use of visualizations in the three areas of the curriculum that we have selected for attention: mathematics, reading, and science. Part III contains two chapters. The first deals with computer-generated visualizations as a special case of visualization found in mathematics, reading, and science and provides some cautions against overenthusiasm about their beneficial effects on learning and recommendations on the use. The second chapter offers some conclusions and recommendations derived from our entire summary and some suggestions about research that might be done.

Part I
An Introduction To Visualization

Part I of this book consists of four chapters. Chapter 1 provides a commonsense review of visualization. We briefly examine mathematics, reading, and science teaching for clear and obvious uses of visualization. The commonsense view is that visualizations provide realistic depictions of the world. Closer examination reveals, however, that for many visualizations realistic depiction is neither their function nor intention. Indeed, they work precisely because of their abstraction and idealization. Chapter 2 provides a history of how visualization entered psychology, beginning with Sir Francis Galton's explorations in the 1890s and tracing a line of research into the twenty-first century and of how it has developed in science, with a reconstruction of views on the use of visualization in scientific writing from Galileo to the twentieth century. The chapter also traces how scientific visualizations become tied closely to computers, but shows how similar issues in creating and interpreting visualizations remain, despite the changing technologies for producing them. Chapter 3 deals with a core issue for the volume—how contemporary theorists conceptualize visualization. The first two questions we address in the book are answered: (1) How is visualization defined in the literature? (2) What constitutes a good visualization, and what is necessary for individuals to interpret and evaluate them? The chapter also outlines the data sources and methods that were examined in answering all five questions. Twenty-eight distinct definitions of visualization were identified in the literature. However, these definitions pointed to a more parsimonious three-fold distinction between visualization objects, introspective visualizations, and interpretative visualizations that simplifies the discussion. Also, we found several useful guidelines, rather than clear-cut rules for dealing with colour, realism, relevance, interactivity, animation, and other characteristics of visualizations that can affect their quality and effectiveness. Chapter 4 looks at the basic mechanisms at work in visualization and shows where there is agreement and where there is disagreement in our understanding of how visualization can work in human cognition. Three alternative theories are presented and discussed and some of their implications for the production of visualization objects are explained.