Sci & Educ (2015) 24:1027–1031
DOI 10.1007/s11191-015-9744-z

BOOK REVIEW

The Use of Multiple Representations as a Tool in Biology Education: Evaluation and Implications for Teaching

David F. Treagust and Chi-Yan Tsui (Eds.): Multiple Representations in Biological Education. Springer, Dordrecht, 2013, ISBN: 978-94-007-4192-8, 390 pp, price $129.00 (Hardcover), $99.00 (eBook)

Gili Marbach-Ad

Published online: 23 January 2015

1 Introduction

For many years, there has been a strong push to change the way students learn science, specifically for the biological sciences. Theories, such as constructivism (e.g., Ausubel 1968; Piaget 1954; Vygotsky 1978), spiral learning (Bruner 1960), and more recently, learning progressions (Duschl et al. 2007), highlight the importance of creating an interactive and engaging experience for students of all ages. Currently, a common understanding exists that in order to induce learning, students need to be engaged in their learning and be able to relate the new knowledge to prior knowledge. The book *Multiple Representations in Biological Education,* edited by Treagust and Tsui, exemplifies how students could be actively engaged in their learning through interpretations and manipulations of models and other modes of external representations (ERs) (e.g., pictures, photographs, maps, and equations).

During the last decade, the emphasis to change science education, which was targeted mainly at the K-12 levels, was extended to the higher education level. The recent report *Vision and Change in Undergraduate Biology Education: A Call to action* [American Association for Advancement in Science (AAAS) 2011] was written with the mission to define curricular and pedagogical goals for undergraduate biology education. The report identifies six core competencies that all undergraduate biology students should develop. One of these competencies is "the ability to use modeling and simulation." This competency is described as follows:

> Biology focuses on the study of complex systems. All students should understand how mathematical and computational tools describe living systems. Whether at the molecular, cellular, organismal, or ecosystem level, biological systems are dynamic, interactive, and complex… (p. 14)

I found this quote appropriate to open this review, since it highlights the main objectives stated by the editors and addressed through the specific collection of essays in the book. Throughout the book, there is an emphasis on the uniqueness of biology as a study of

G. Marbach-Ad (✉)
College of Computer, Mathematical and Natural Sciences, University of Maryland, College Park, MD 20742, USA
e-mail: gilim@umd.edu

complex systems that builds on multiple organization levels (molecular, cellular, organismal, and ecosystem) and representations (realistic vs. abstract) that requires the understanding of the relationships between them (see chapter by Schonborn and Bogeholz in the reviewed volume). There is also a focus on the interdisciplinary nature of biology, showing that the interpretation of biological phenomena requires integration of knowledge from multiple scientific (e.g., physics, chemistry, and mathematics) and non-scientific (e.g., history and philosophy) disciplines.

The book is divided into three parts. The first includes essays that reflect the role of ERs in learning biology. The second part provides examples for possible implications of using multiple ERs for biology teachers. The third part contains essays that discuss methods and challenges to assess the effectiveness of teaching and learning with ERs. In the pages to follow, I start with a discussion about the uniqueness of the biology discipline and then organize the review according to the themes of the three parts of the book. It is important to mention that most of the essays touch on more than one theme.

2 The Uniqueness of the Biology

In their introduction to the book, Treagust and Tsui present a three-dimensional theoretical model for learning biology with multiple ERs—the cube model. The cube represents three types of translations: (1) domains of knowledge in living systems (e.g., evolution, homeostasis, and development); (2) representation modes used in biology (e.g., photographs, maps, graphs, and equations); and (3) organization levels in biology (e.g., macro, micro, submicro, and symbolic).

In my opinion, this model brilliantly demonstrates the uniqueness of biology as a discipline and highlights the complexity of teaching biology. Biology is a field that is constantly evolving. The organization levels that are shown in the third face of the cube are not only representing the way that biology is taught, but they are also analogical and parallel to the development of biological research and discoveries throughout the history. With the development of advanced research tools and equipment (cameras, microscopes, optic fibers, and computer programs), scientists discovered microscopic levels that could only be speculated before or described through symbolic representations. For example, the concept of gene was coined and used in research in the beginning of the twentieth century, long before there was any evidence about its material constitution.

In biology education, research shows (e.g., Stover and Mabry 2007) that students develop alternative conceptions similar to views of scientists of the past, as a result of their struggle to understand the different levels of organization. Alternative conceptions in biology are often related to the difficulties to connect between levels of organizations. Schonborn and Bogeholz (in the reviewed volume) claim that different modes of ERs (realistic vs. abstract) can help students to integrate knowledge from different levels of biological organization, including subcellular, cellular, organ, organism, and population levels. Schwartz and Brown bring in another chapter in the volume examples for alternative conceptions in respiration and photosynthesis that originate mainly due to students' difficulty to link between the different levels of organization. They also highlight the interdisciplinary nature of biology. They provide examples for biological phenomena the explanations of which are drawn from other fields of sciences, like chemistry, physics, mathematics, and engineering. Such interdisciplinary connections add more complexity to students' understanding.

3 The Role of External Representations in Learning Biology

ER modes are used in both science and science education. Since most scientific phenomena cannot be displayed directly and in a concrete manner, ERs are often used to describe, explain, or predict them (Gilbert 2005). ERs that are developed for educational purposes are specifically designed to aid students to understand scientific consensus models or scientific phenomena and concepts. While researching the use of ERs in generating phylogenetic trees, Halverson and Friedrichsen conclude in another chapter of the book that visual representations enhance learning from texts, improve problem solving, and facilitate developing connections between new knowledge and prior knowledge. In another chapter, Horwitz highlights the advantages of using computer simulations or animations to teach biology topics. Horwitz emphasizes that there are topics in biology, such as evolution, that are ideally suited to teaching with computer animation, "which can transcend space and time constraints to model processes that take place on scales from molecules to ecosystems and over times ranging from milliseconds to billions of years" (p.129).

While ERs hold an important role in teaching biology, researchers argue that complex learning environments of multiple representations sometimes may hinder students' learning. In another chapter, Eilam indicates five characteristics that we want to examine before we use ERs in a learning environment: *learner's characteristics* (e.g., prior knowledge and abilities); *the representation characteristics* (e.g., abstraction and cognitive load); *characteristics of the pedagogy* (e.g., interactive vs. passive); *contextual characteristics* (e.g., students' sociocultural background and their attitudes and beliefs toward science); and *status and placement in the horizontal and vertical school curriculum* (e.g., transfer the understanding of one representation to the interpretation of another more complex one).

4 Implications of Using ERs for Biology Teachers

For the past 10 years, I have been involved in providing professional development for preservice teachers and instructors in higher education. We encourage biology instructors to implement active learning, student-centered teaching approaches, including the use of ERs in the classroom. However, the literature shows that while utilizing ERs in classrooms, the role of the teacher is critical in order to make learning meaningful (as discussed by Yarden and Yarden in the reviewed volume). Yarden and Yarden consider how using animations affects high school students' comprehension of biotechnological methods. They conclude that the teachers had a crucial role in such activities. The animations alone did not enhance students' comprehension and critical thinking, as well as the combination of animations with accompanied assignments and inquiry questions. In another chapter, Roth and Pozzer-Ardenghi stress the importance of the social interaction when working with ERs. They assert that students learn the most from representations while interacting with their peers or their teachers.

In designing ERs, teachers need to consider learning theories. One such theory is the cognitive theory of multimedia learning (Mayer and Moreno 2002). The cognitive theory of multimedia learning highlights the importance of incorporating visual and verbal presentations, selecting relevant material, and organizing it to a coherent representation. While using ERs, teachers also need to consider the context of their students, such as age, gender, and prior knowledge.

Some of the essays in the book analyze ERs in biology textbooks. All too often, the material in biology textbooks is presented as fragmented pieces of information (as discussed in this book by Buckley and Quellmalz, and Roth and Pozzer-Ardenghi), and students struggle to connect the different representations that are introduced in the textbook. As a result, they are failing to develop a coherent understanding of the subject matter. Biology is a domain that is based on theories and principles that are shared by many organisms and phenomena, and therefore, textbooks should use numerous representations that share similarities to help students learn broad principles that could apply to the understanding of many biological phenomena (as argued by Eilam in the reviewed volume).

In many cases, the use of ERs could promote students' understanding of the nature of science (NOS) or the history of science. Wong, Cheng, and Yip decided (as described in their chapter) to use the severe acute respiratory syndrome outbreak in Hong Kong to represent a common epidemic system in biology. They investigated how biology teachers handle scientific models (rather than merely teaching models). As a result of their study, they recommended the use of more authentic scientific models to develop students' interest and their understanding of the inquiry and the dynamic NOS.

5 Assessing the Effectiveness of Teaching and Learning with ERs

The term evidence-based teaching approaches became a buzzword, to imply that when we implement new teaching approaches in the classroom, we need to choose methods that were proven effective to have the highest impact on students' learning. This is the theme of the third part of this book—a discussion on how to assess the effectiveness of using ERs in biology education. Throughout the book, authors describe different assessment methods that they used and often discuss the challenges to assess the ERs that they were using. Part of the challenge to evaluate the effectiveness of ERs is that it requires first to carefully articulate the specific goals or research questions and then to find the appropriate assessment methods to respond to these questions. When we use ERs, we have multiple factors and multiple tiers that we would want to research. One research question can relate to the students' ability to visualize and interpret an ER. Another research question can probe how students apply knowledge from one representation to other modes of representations or from one biological system to another.

In her chapter, Phyllis Griffard points out that educators should clarify to their students that the overarching goal of learning with ERs is understanding, "not simply encoding or restating the propositions represented" (p. 180). However, she raises the challenge to assess whether students reach that goal. She claims that although interviews and "think aloud" procedures are helpful, they could be misleading, because converting thoughts to verbalizations change the cognitive process and does not show the ways in which students interpret the representations.

Anderson and colleagues present in their chapter the CRM model to consider factors that affect students' ability to interpret, visualize, and learn from ERs. The CRM model consists of three factors and their interrelationships: (1) conceptual knowledge of students that is relevant to the representation; (2) reasoning, making sense of the ER; and (3) mode, understanding the symbolic markings of the ER. The researchers state that the CRM model helps them in assessing students' learning. The factors in their model direct them to articulate their research questions or goals that they want to achieve (e.g., conceptual understanding and reasoning ability), and according to these goals, they define the assessment methods that they will use.

A battery of quantitative and qualitative assessment tools is presented in the book by different authors. Most authors present more than one tool to measure the impact of using ERs on students' learning. For example, Buckley and Quellmalz researched the impact of using computer-based simulation and representation to teach biology to high school students. To provide evidence of learning, they videotaped 160 h that captured classroom activities and group activities, collected and analyzed students' worksheets and presentations, interviewed students, and analyzed classrooms pre- and post-tests.

6 Concluding Thoughts

I find this book a much-needed collection of resources and supportive research. Treagust and Tsui gathered under the same roof remarkable and thoughtful examples for using ERs in the classroom. They bring evidence for successful models for teaching with ERs, but also tackle the challenges to use ERs and assess their effectiveness and impact on students' learning. The book provides a comprehensive theoretical background, in addition to multiple practical examples that teachers could adopt in their classrooms.

References

American Association for Advancement in Science (AAAS). (2011). Vision and change: A call to action. Washington, DC.

Ausubel, D. (1968). *Educational psychology: A cognitive View*. New York, NY: Rinehart & Winston.

Bruner, J. (1960). *The process of education*. Cambridge, MA: Harvard University Press.

Duschl, R. A., Schweingruber, H. A., & Shouse, A. W. (2007). *Taking science to school: Learning and teaching science in grades K-8*. Washington, DC: National Academies Press.

Gilbert, J. K. (2005). *Visualizations in science education*. Dordrecht, The Netherlands: Springer.

Mayer, R. E., & Moreno, R. (2002). Animation as an aid to multimedia learning. *Educational psychology review*, *14*(1), 87–99.

Piaget, J. (1954). *The construction of reality in the child*. New York, NY.: Routledge.

Stover, S. K., & Mabry, M. L. (2007). Influences of teleological and Lamarckian thinking on student understanding of natural selection. *Bioscience: Journal of College Biology Teaching, 33*, 11–18.

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press.