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What do diagrams reveal? A comparative analysis of impact of different external representations on conceptual understanding

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Abstract: Learning is both guided by and constrained by the features of the external representation (ER) used for developing conceptual understanding. This work uses a case-study design to study three groups of 5 pre-college biology students (n=15) who used three different ERs- *concept-map*, *symbolic model* and *molecular model*, to perform tasks related to the structure of the DNA (Deoxyribonucleic acid) molecule. A descriptive synthesis analysis of students' diagrams revealed ER-specific changes in their conceptual knowledge.

Introduction

As science education researchers and practitioners, we use different external representations (ERs) to influence the processes and outcomes of learning. These representations carry some aspect of the represented concept and there are some aspects which are specific to the representation itself (Palmer, 1978). This is one of the reasons why different ERs provide different extent of support to the process of learning (Scaife & Rogers, 1996). And, hence, we have literature reporting different ERs, like concept maps (Novak & Gowin, 1984), diagrams (Kindfield, 1994), models (Malacinski & Zell, 1996; Srivastava, 2016), animations (Falvo, 2008) and others, to have wide-ranging impact on students' learning. The present study makes a move in this direction and tries to elicit the influence of specific features of three different ERs-*concept-map*, *symbolic model* & *molecular model*, on learners' ability to both visually and verbally manifest their conceptual understanding about one specific biological concept. Since concepts in Genetics are known to be difficult, especially the ones concerning structural and dynamic aspects of biomolecules (Lewis & Kattmann, 2004; Tang & Teng, 2005), this study focuses on the structure of one of the most complex biomolecules that holds our genetic information- the Deoxyribonucleic acid (DNA).

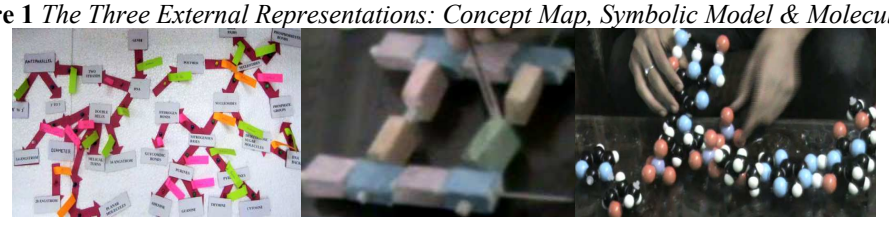
Theoretical Framework

This study relies on the power of student-drawn diagrams as windows into students' extant conceptual understanding and to capture conceptual shifts that an intervention generates. This reliance is theoretically grounded in multiple strands of literature that use student-generated diagrams to measure thought processes & way of reasoning (Schönborn & Anderson, 2009; Schwonke, Berthold and Renkl, 2009). The overall workflow of the study follows the principles of 'descriptive syntheses' proposed by Schönborn & Anderson (2009), where student-generated data (here, pre- and post-intervention diagrams) is studied to reveal and describe students' understanding and the differences that emerge from the groups.

Methods

Fifteen pre-college and college biology students participated in the study and all of them provided their written consent for the same. The study followed a case-study design, where interactive sessions were closely followed through video recordings and notes. Three groups of five students each (3*5) were asked to work with one of the three ERs (see Fig. 1), sandwiched between two diagram-making sessions, where individual students were asked to draw a diagram of the 3-D structure of the DNA molecule.

Figure 1 *The Three External Representations: Concept Map, Symbolic Model & Molecular Model*



The concept map group was asked to construct a concept map (see sample in Fig. 1, left picture) using given type-written concept cards (n=36) related to the DNA structure and to specify linking phrases using pin-up labels. The symbolic model group was asked to dissect the given symbolic model (see Fig. 1, center) made from knitting needles and colored styrofoam blocks, to identify 5 DNA structural elements: nucleotide, nucleoside,

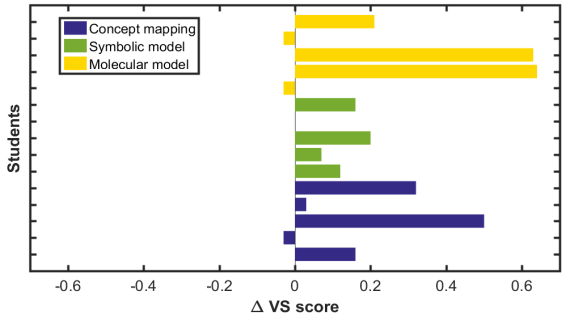
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nitrogenous base, phosphate group and deoxyribose sugar molecule. The molecular model group was asked to dissect the given molecular 3-D model (see Fig. 1, right), made from colored balls, to identify similar DNA structural elements as in the symbolic model dissection task.

Analysis & Findings

The pre- and the post-task diagrams of each student was analyzed to compute a quantitative measure of diagrammatic competence- the verbal-spatial (VS) scores. VS-scores were calculated per diagram by dividing the number of concepts represented verbally (through labels) and spatially (marked using arrows) divided by the total number of concepts represented in the diagram. We illustrate the change in students' VS scores (plotted on X-axis in Fig. 2) in their diagrams for the three groups (Fig. 2). Overall, we found that the interventions led to enhanced verbal-spatial performance in 73% of students in the post-test diagrams. However, the effect of molecular models was more pronounced than concept-maps and symbolic models. We also found several representation-specific errors and corrections which were correspondingly absent or present in the post-task diagram. For instance, all participants of the concept-map group either incorrectly mapped or did not use the 'planar molecule' concept card, likely because they did not realize that DNA base pairs are 'planar' or flat structures. In another instance, all the symbolic modelers got the four nitrogenous bases correct, while all the molecular modelers got it wrong. This can be attributed to the difference in the visual affordances of the models.

Figure 2 *Improvement in Verbal(V)-Spatial(S) Scores for all the three groups*



Low VS scores signify the missing link between students' understanding about specific concepts and their spatial locations, and along with the ER-specific errors, can act as cues to help instructors identify difficult concepts and improve the pedagogical process.

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