How to 'Catch' a Virus: Representational Affordances in a Middle-School Introduction to Nanoscale Self-Assembly

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1. OBJECTIVES

Nanoscale concepts are principally taught at the post-secondary level (Uddin & Chowdhury, 2001) and current educational standards for U.S. middle schools do not directly address nanoscale science (AAAS, 2001; NSES, 1996). However, recent scientific and commercial interest in nanoscale science and engineering have led to multi-agency programs funding research in K-20+ learning and teaching about these phenomena (Roco, 2002).

One of the main challenges of teaching nanoscale science is that the phenomenon is so small, learners are unlikely to have had prior first-hand experience with it, even with the use of instruments such as microscopes. Thus, instruction of nanoscale phenomena could be facilitated using accessible *representations* of the concepts. The present work is focused on representations that could support learning about *self-assembly*, a nanoscale phenomenon in which the disordered components of a pre-existing system form ordered structures or patterns upon reaching an equilibrium state. This reversible process occurs without external manipulation of the components, and can be predicted based on an understanding of the components and their environment (Whitesides & Grzybowski, 2002).

Self-assembly can be viewed as a set of general relations that are largely instantiated in the context of specialized domains (such as molecular biology or electrical engineering), such that no one is an expert in self-assembly per se, but in the application of its principles to a specific domain where self-assembly processes either occur naturally or can be "engineered" to achieve some practical purpose. Thus, in early learning about self-assembly, it is important to ground the phenomenon in a particular application, one that is readily accessible to novice learners. The current work is focused on one such application: the design of single-strand DNA to detect viruses. This topic appears well-suited for the purpose, since middle-school students are familiar with viruses and understand the need to detect them. The design approach was chosen as a vehicle for instruction—as opposed to didactic presentation or procedural training—with the consideration that the active construction of meaning involving first-hand experience with representations would support learning about these concepts.

The learning goals of the current study include (a) that a single strand of DNA can catch another (viral) single strand, (b) that each strand is composed of nucleotides containing one of four bases: Adenine (A), Thymine (T), Cytosine (C), or Guanine (G), (c) that these nucleotides will selectively attract and bond with other nucleotides (base-pairings: A with

T, C with G), and (d) that this process is used to 'detect' viruses and happens at nanoscale. The challenge of the study is in developing representations that effectively convey these goals.

This paper presents observations from a pilot study conducted in a 7th-grade classroom, in an effort to explore the affordances of various representations and their impact on students' learning. The goal was to gain tentative insights on the adequacy of the representations, the effectiveness of the instructional scaffolding that supported students' design activities, and how well the students learned the concepts presented.

2. PERSPECTIVE

Research in science education has demonstrated the use of metaphors in constructing meaning via the direct comparison of mental models with actual life experiences (Newton & Newton, 1995). Models are sets of representations of systems and reasoning structures that allow understanding, predictions, and explanation of scientific phenomena. The use of models and the process of modeling are fundamental aspects of science learning and instruction, particularly with respect to abstract concepts (Schwarz & White, 2005; Hestenes, 1993; Mayer, 1989).

Using different scientific representations to represent the same phenomena supports the construction of meaning by inviting a variety of perspectives and appearances (Harrison & Treagust, 1996, 2000; Treagust et al., 2002). Representations in nanoscale science instruction are particularly useful because the instruments to explore and study these phenomena are not widely available (Daly & Bryan, 2007; in preparation).

In recent years, Boulter and Buckley (2000) created a typology that categorizes representations based on their physical properties and, importantly, organizes them in terms of whether they are quantitative or qualitative, static or dynamic, and deterministic or stochastic. The current work takes this typology into consideration, and explores the use of printed diagrams, beads, and computer-simulation in terms of their associated flexibility and constraints that may influence students' design outcomes.

3. METHOD

Participants

Eight 7th-grade students were recruited from an urban classroom in Chicago. Students were randomly paired at the beginning of the study, and were asked to remain in pairs throughout the design tasks.

Materials

A *printed diagram* representation was created using printed circles of DNA sequences representing a target virus, and color-coded stickers representing the nucleotide bases (A, C, G, or T). Students were free to place the colored stickers anywhere within the result space. A *beads* representation was constructed using plastic colored pop-beads. The red and yellow beads contained embedded polarized magnets (representing C and G); the blue and green beads had Velcro glued to the surface (representing A and T). This construction implemented the nucleotide base-pairing rules: the beads with the magnet could not be paired with the ones with Velcro, magnets of the same polarity could not be paired, nor could Velcro of the same "polarity."

A computer environment was developed, simulating two DNA strands in liquid. The simulation allows users to add DNA bases represented as four color-coded circles with a letter in the center (A, C, G, or T). With a mouse click, the bases are added to the section with the liquid solution and the simulation automatically forms the 'catcher' sequence from the added bases. When the catcher sequence is ready, the simulation can be run to observe if the target virus gets attracted to the catcher strand. The simulation (instead of the user) controls the motion of the catcher and viral strands.

Procedure

Following an introductory lesson presenting terminology and key concepts, students were separated into either a *printed diagrams* or *beads* condition. For each representation type, students were asked to design 'helper strands' which, when attached to a substrate, would 'catch' a targeted virus through nucleotide base pairings. The length of the catcher was an important factor of the design: the optimal catcher should have not only accurate base pairings, but also the fewest number of bases that can still uniquely catch one of the viruses.

The study was conducted in two phases. In phase one, students in the printed diagrams and beads conditions received two viral strands. They were asked to apply the concepts from the introductory lesson to design a chain of DNA (virus 'catcher') to uniquely capture only one of the two viruses. In phase two, all students were given the computer simulation and were asked to complete the same virus-catching task using two novel viral sequences.

4. DATA SOURCES

The observations reported below were based on students' virus-catching design activities. Of particular interest were a) students' collaboration and role distribution in accomplishing the design tasks, and b) the values and constraints of the representations in influencing students' design processes. (Pre- and post-tests of conceptual understanding were also administered, but are not the focus of the present analysis.)

5. OBSERVATIONS

Collaboration and Role Distribution

The affordances of the different representations appear to have different effects on student collaboration. Students using printed diagrams initially worked in pairs and created a long strand to pair the entire viral sequence. However, as the task progressed and they were asked to improve the optimality of their design, a lack of collaboration was observed, which may be due to the observed difficulty in discussing the task using this representation. Furthermore, the printed diagram representation is oriented in a single direction (i.e., it can only be viewed from the same location at a given time), resulting in individual "ownership" of the task. In comparison, the beads were visible from all directions, allowing students who were positioned at different places on the table to work with them simultaneously throughout the task (e.g., one student holding the target virus, another aligning and attaching helper chains). Students using beads also engaged in more conversation, by discussing their decisions and comparing their designs with those of the other students. In the computer simulation phase, students were also collaborative, but tended to employ a single "operator", perhaps due to the single mouse that can only be used serially.

Extrinsic and Intrinsic Constraints of Representations

Observations from the virus-catching activities suggest two classes of constraints associated with the representations. *Extrinsic constraints* were constraints that were external to the representations, including the effectiveness of the representations in serving instructional purpose and students' prior familiarity with the media. *Intrinsic constraints* were constraints that were built into the representational instruments. These classes of constraints are described in more detail below.

1. Extrinsic constraints. When students using printed diagrams were asked to improve the optimality of their catcher, they removed some of the stickers, resulting in incorrectly unlinked stickers (Figure 1). Thus, this representation appears inadequate for conveying the concept of *continuity* in DNA strands. In comparison, constraints involving prior experiences appear to be associated with the beads. Students' familiarity with like objects (necklaces, chains, etc.) may have supported the intuition that they needed to link the beads, forcing continuity of the viral strand (Figure 2).

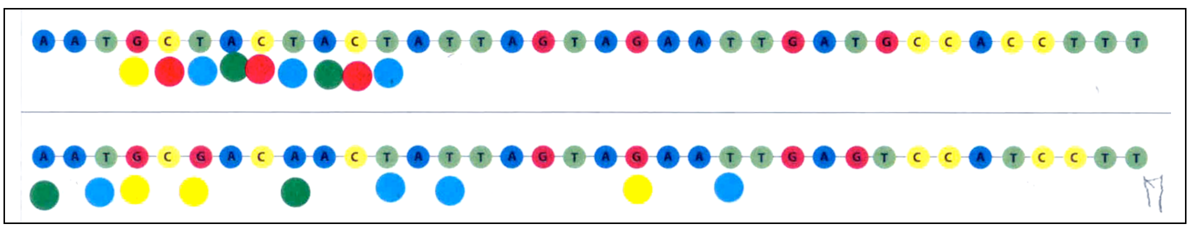

Figure 1. Students' design with the printed diagrams, showing low catcher efficiency (above) and non-sequential strand (below).

Figure 2. Students' design with the beads, showing sequential strands.

2. Intrinsic constraints. As mentioned above, beads allow for multiple perspectives of the representation. Students using this representation were able to check the quality of their design by dynamically aligning the catcher with the virus at different points in the strand. This flexibility allowed students to confirm whether their catcher was capturing only the section of the target virus that was uniquely different from the other virus. In contrast, the rigidity of the printed circles in the printed diagram representation did not allow for such rich perspectives and manipulation. Moreover, although students using the printed diagrams were highly accurate in applying the base pairings, the mutually exclusive nature of the magnet and Velcro pairings in the beads may have provided additional helpful constraint in students' matching.

Finally, the self-assembly process does not require direct manipulation of the components. Due to the nature of the three representations, only the computer simulation in phase two of the study succeeded in conveying this concept. This representation helped students to discover how the strands will attract *each other* if the design is paired correctly (Figure 3).

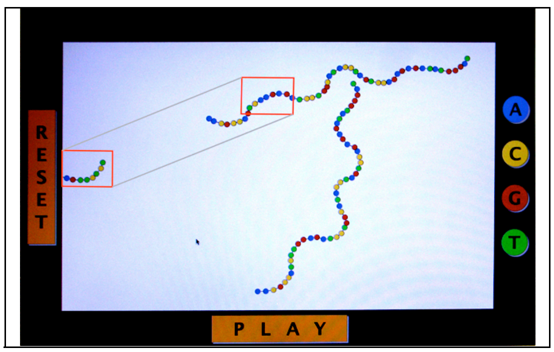

Figure 3. Students' design in the computer simulation.

6. CONCLUSIONS AND FUTURE WORK

Preliminary observations from the current study suggest that the different models used to introduce self-assembly using the application of DNA virus detection afforded different constraints on learning and design. The major error observed with the use of printed diagrams involved the creation of unconnected nucleotide chain segments, suggesting an extrinsic lack of instructional support in conveying connectivity. The constraints imposed by the computer simulation did not allow such an error to be generated, but interestingly, the error also did not arise in the beads representation, suggesting a sub-class of constraint that may be based on students' prior experiences with the media (i.e., beads create connected chains rather than segments). Media differences also impacted role distribution: the printed diagram activities tended to be undertaken in isolation, simulations were collaborative but employed a single "operator", and beads were interactively manipulated by pairs of students.

Future directions include a full study using printed diagrams, beads, and computer simulation as parallel conditions (instead of sequential phases). A separate study will also manipulate the complexity level in the computer simulation.

It will also be important to examine more closely the impact of using multiple representations on learning, particularly how differences in the affordances might influence cognitive load by forcing additional mappings (representation-to-representation as well as representation-to-phenomenon), or whether the complementary strengths of different representations might compensate for limitations of individual representations.

In closing, these observations contribute to the understanding of students' construction of meaning with the use of representations, and the affordances of each representation in supporting instruction of nanoscale phenomena.

REFERENCES

American Association for the Advancement of Science, Project 2061. (2001). *Atlas of Science Literacy*. AAAS and NSTA, Washington DC.

Boulter, C., & Buckley, B. (2000). Constructing a typology of models for science education. In J. K. Gilbert & C. Boulter (Eds.). *Developing Models in Science Education*. Dordrecht: Kluwer.

Daly, S., & Bryan, L. (2007). Models of nanoscale phenomena as tools for engineering design and science inquiry. Paper presented at the annual meeting of the American Society for Engineering Education.

Harrison, A. G., & Treagust, D. F. (1996). Secondary students' mental models of atoms and molecules: Implications for teaching chemistry. *Science Education, 80*, 509-534.

Harrison, A. G., & Treagust. D. F. (2000). Learning about atoms, molecules, and chemical bonds: A case study of multiple-model use in grade 11 chemistry. *Science Education, 84*, 352-381.

Hestenes, D. (1993). Modeling is the name of the game: Conceptual models and modeling in science education. Paper presented at the NSF Modeling Conference.

Mayer, R. E. (1989). Models for understanding. *Review of Educational Research, 59*, 43-64.

National Science Education Standards. (1996). Washington, DC: National Academy Press.

Newton, D., & Newton, L. (1995). Using analogy to help young children understand. *Educational Studies, 21*, 379.

Roco, M. (2002). Report, Nanoscale science and engineering; United States (2001–2002). *Journal of Nanoparticle Research, 4*, 271–274.

Treagust, D., Chittleborugh, G., & Mamiala, T. (2002). Students' understanding of the roles of scientific models in learning science. *International Journal of Science Education, 24*, 357-368.

Uddin, M. & Chowdhury, A. R. (2001). Integration of nanotechnology into the undergraduate engineering curriculum. *Proceedings of the International Conference on Engineering.*

Schwarz, C. & White, B. (2005). Metamodeling knowledge: Developing students' understanding of scientific modeling. *Cognition & Instruction, 23*,165-205

Whitesides, G. M. & Grzybowski, P. (2002). Self-assembly at all scales. *Science, 295*, 2418-2421.