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EDUCATION FORUM

DO TEXTBOOK DIAGRAMS REALLY ENHANCE STUDENT LEARNING?

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Over the years, the exponential growth of the field of biochemistry and molecular biology research has led to the production of more extensive textbooks, designed to communicate the vast amount of new information that students are expected to learn. At the same time, textbook authors have attempted to find better ways of illustrating the various cellular and molecular structures and processes. These have included the use of more colourful and attractive diagrams, as well as CDs of computer-generated images, usually prepared by an artist in communication with the author. In this regard, it is fair to say that the outcome of these endeavours has produced some truly beautiful textbooks with visual displays that are certainly aesthetically pleasing to the eye and, on the whole, considered by experts to be very useful for their teaching function. But the following crucial questions arise: do textbook authors check whether such diagrams, and other visual displays, actually enhance student learning and conceptual understanding and, if so, what methods have they used to screen diagrams and what results have they found? In this article we briefly address these questions in the light of our own research on diagrams and our knowledge of other work done in the field.

Firstly we believe that no biochemistry textbook authors to date have used research to screen for the usefulness of their diagrams simply because, to our knowledge, there is only a handful of researchers in the world who are doing any sort of biochemistry education research and none of them are authors of textbooks. We do believe that several textbook authors have made use of diagrams developed during many years of teaching experience and, therefore, believe intuitively that they are useful as teaching tools. However, research on diagrams has shown that this is not necessarily the case. For a start, extensive investigations have shown that there is a big difference in how experts and novices use and learn from diagrams. This is because experts usually have far more developed diagram-processing skills and necessary conceptual knowledge, required for interpreting the diagram, than do students. For this reason it is wrong for experts to assume that because they think a diagram is a good one that it will necessarily be good for students- this needs to be checked using appropriate screening methods.

Our science education research group (SERG) has developed research methods for evaluating the usefulness of diagrams as learning tools (Schönborn et al., 2002b; Grayson et al. 2001). Application of these methods to various diagrams, from established textbooks in the field, have revealed a wide range of student difficulties with the interpretation of diagrams (Schönborn et al. 2002a), which can be added to a host of other difficulties already reported in the literature. On researching the source(s) of such difficulties we have found a wide range of potential sources, both from our own results and those of others in the field. These include the following:

- Personal factors such as motivation to understand the diagram and learn from it;
- Experience in constructing, reading and interpreting diagrams (Lowe, 1989);
- Intellectual skills of the student (Gillespie, 1993);
- Ability to construct mental images of the phenomenon using the diagram (Lowe, 1993);
- Student's content/conceptual knowledge related to context of diagram (Lowe, 1993; Henderson, 1999; Alesandrini, 1984);
- Spatial visualisation ability e.g. width, depth, height, rotation of 3-D molecular structures (Shubbar, 1990);
- Students thinking the diagram is "visually true" and taking it at "face value" or literally (Hill, 1988; Wheeler & Hill, 1990);
- Reasoning ability e.g. diagrammatic, surface-level, analogical;
- Ability of student to transfer their knowledge from one diagram to another;
- Quality of diagram design (Lowe, 1993);

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- Lack of diagram conventions (e.g. symbols), or use of ones that are often not universal or consistent (Wheeler & Hill, 1990);
- Understanding of conventions (Henderson, 1999) and limitations of diagram;
- Amount of detail represented (level of abstraction) (Holliday, 1975);
- Diagram density and compression (Hill, 1988);
- Extreme use of colour (Holliday, 1975; Alesandrini, 1984); and,
- Representation of structure and function in same diagram.

Based on the above, and other information, we have formulated and validated a 3-factor model (Schönborn et al., 2002b) of the major categories of factors affecting students' ability to interpret diagrams. This includes students' conceptual knowledge (e.g. misconceptions) required to interpret the diagram, students' ability to reasoning with both the diagram and their conceptual knowledge, and the mode in which the diagram itself is presented (i.e. is it a good or bad diagram). Our methods are able to yield research data that determines which of these 3 factors is the dominant problem with respect to a particular diagram and group of students. This information is then being used to inform the design of teaching approaches to remediate (correct) or prevent difficulties as well as tasks that make use of the diagrams to enhance student learning. Based on our own experience and research results and those reported in the literature we currently recommend teachers and their students try the following approaches:

- Explain the context of the diagram and what it represents;
- Explicitly teach the features and conventions in diagrams to students;
- Give them tasks that promote deeper, rather than superficial, thinking about what the diagram represents;
- Encourage them to think about underlying reasons when manipulating diagrams e.g. equations;
- Expose them to different diagrams of the same phenomenon (Vonder et al., 1998);
- Enhance links between abstract, stylised, and realistic-type diagrams of the same phenomenon;
- Encourage translation across diagrams of the same phenomenon;
- Teach students the necessary diagram-processing (reading) skills (Hill, 1988; Lowe, 1989; Henderson, 1999);
- Encourage them to visualize phenomena being represented;
- Use tasks that develop their spatial skills (Lord, 1987, 1990);
- Give tasks that develop their ability to both interpret (Holliday, 1975) and draw (Lowe 1993) diagrams;
- Remember that they have no everyday experience with abstract phenomena;
- Give tasks requiring students to analyse and discuss diagrams (Barlex & Carre, 1985)
- Be aware of their existing (prior) conceptual knowledge when exposing them to diagrams (Henderson, 1999);
- Realise differences between experts and novices w.r.t. interpreting diagrams;
- Promote active interaction between students when they are drawing and interpreting diagrams (Lowe, 1987).

Textbook authors might argue that logistically it would be an impossible task to screen all their diagrams using the research methods mentioned above. This might be true but equally so they are, by publishing the textbook as an educational aid, effectively claiming that the material presented will successfully enhance student learning of the topic. Indeed authors of research papers are expected by the community of scientists to justify the validity of their results- why should the same principles not apply to material presented in textbooks? Having said this, I do acknowledge that it would not be practical to perform research studies on every diagram. For this reason a major outcome of our research is to establish key criteria by which we believe diagrams and other visuals could be more easily screened. We also intend using research results to inform guidelines for diagram design and for the presentation of textual and other materials in textbooks. In this regard the following are some

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of the ideas we have formulated from our own research and from reports in the literature:

- Standardise diagrammatic conventions;
- Ensure that the diagram is not too complex nor too simple for the purpose in mind;
- Determine diagram detail by educational aims, prior knowledge and interaction time (Holliday, 1975);
- Relate diagram complexity and simplicity to comprehension;
- The mode of representation must be appropriate for what is being represented;
- Communication between content experts and design experts is crucial (Lowe, 1993);
- Effectiveness of a diagram also determined by the characteristics of the learner;
- What the diagram intends to illustrate should equal what is perceived (Wheeler & Hill, 1990).

With the field of visual aids rapidly expanding into the development of animation, simulation, and virtual reality programs, the same question that applies to diagrams will also be of relevance to these new visualization tools: do they enhance teaching, learning and understanding of science? And if they don't, how can we modify them or introduce new visualization tools that might better achieve our goals? These questions, and other related ones, are some of the targets of the rapidly developing field of visualization in the life sciences. This is an area which offers exciting challenges to experts from a broad range of disciplines besides life science, including science education, cognitive psychology, media studies and computer science and technology.

References:

- Grayson, D.J., Anderson, T.R., & Crossley, L. G. (2001) A Four-Level Framework for Identifying and Classifying Student Conceptual and Reasoning Difficulties. International Journal of Science Education 23 (6), 611-622.
- Schönborn, K. J., Anderson, T.R. and Grayson, D.J. (2002a) Student difficulties with the interpretation of a textbook diagram of immunoglobulin G (IgG). Biochemistry & Molecular Biology Education, 30 (2), 93-97.
- Schönborn, K.J., Anderson, T.R.& Grayson, D.J. (2002b) Developing and testing a model of the factors affecting student interaction with scientific diagrams, In C. Malcolm and C. Lubisi (Eds), Proceedings of the Tenth Annual Meeting of the Southern African Association for Research in Mathematics, Science and Technology Education, University of Natal, Durban, 22-26 January, 2002, Section III, pp. 377-383.
- Other cited references available on request

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