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Misconceptions in Photosynthesis: the Use of Novel Database Software

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RESEARCH ISSUES

The aim of this research is to explore the use of *Bioview*, an information handling package specifically written for use in biology education, as an aid to students' understanding of science concepts. A database concerned with photosynthesis provides a focus for the research. The software uses a novel pictorial approach to represent data corresponding to three interacting variables, and runs within the graphical user interface provided by Microsoft *Windows*. Thus this research spans two areas of interest: (i) students' understanding of science concepts (particularly those concerned with photosynthesis), and (ii) users' interactions with graphical user interfaces. Of particular interest is the interplay (positive and negative) between these two areas.

BIOVIEW: A NOVEL INFORMATION HANDLING PACKAGE

Bioview is based on the idea of a "datacube". Each axis of the datacube represents a variable. The intersections corresponding to discrete values of the variables form a three dimensional data grid. The datacube can be "sliced" along each axis to look at any one of three orthoganal sets of datasheets. Any row or column in the chosen datasheet can be selected and graphical and/or statistical information corresponding to the row/column can be requested. The datacube is represented pictorially in a window displayed on the screen. Slices of the cuboid are selected by clicking and dragging "sliders" associated with each axis. Other windows show graphical and statistical representations. As a datasheet is sliced or rows/columns are selected the other windows are updated. This produces an animated display.

Figure 1 shows a photosynthesis datacube of rate of photosynthesis values corresponding to different values of temperature, carbon dioxide concentration and light intensity (as represented by the three axes). Note that the relative size of each axis represents the relative size of the dataset corresponding to each variable. The datasheet shown in the figure corresponds to a fixed value for the concentration of carbon dioxide and a row has been selected which would show the variation in the rate of photosynthesis with light intensity for the temperature corresponding to the row.

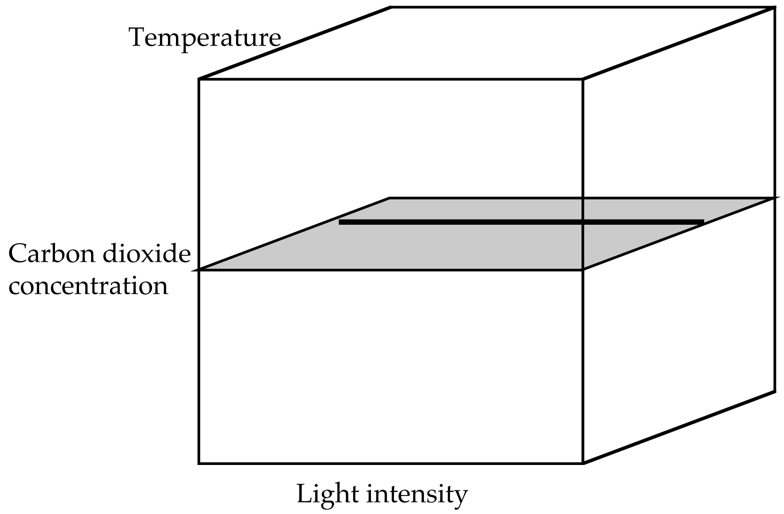

Figure 1: A photosynthesis datacube

A THEORETICAL FRAMEWORK

Birnbaum (1990) provides a general framework for students' use of software which can be used to structure the areas of interest in this research. He distinguishes three types of activities associated with the use of information technology (IT) by students: task intrinsic activities, computer intrinsic activities, and IT applicational activities. In the context of this research task intrinsic activities would be concerned with learning science, with a particular reference to an understanding of photosynthesis; computer intrinsic activities would be concerned with the manipulation of the graphical user interface; and IT applicational activities would be concerned with the use of the software (particularly the novel pictorial database representation) to learn relevant concepts in science.

Task intrinsic activities

These activities would be those concerned with completing the task in hand; gaining an understanding of photosynthesis. Some of these activities would be specific to learning about photosynthesis, whilst others would be concerned with more general aspects of understanding science. For example a task in the former category could be an investigation of the significance of carbon dioxide concentration, whilst a task in the latter category might relate to the development of strategies for the investigation of the relationships between variables. Thus this research is concerned to identify evidence for (i) the development of both specific and general concepts and skills in science, and (ii) the interaction between specific and general concepts and skills.

Computer intrinsic activities

There are two distinct aspects to the manipulation of this software. The software design makes use of many of the features available in the *Windows* 'desk-top' graphical user interface, e.g. multiple overlapping windows that can be sized by the user, and multitasking. In addition, databases are represented pictorially as datacubes, with the user able to look for patterns in the data by moving 'slices' through the cube in the three directions parallel to each axis of the datacube. Students are thus required to use two graphical metaphors in concert: the desk-top metaphor to enable basic manipulation of the system and the datacube metaphor to allow exploration of the database. This research is concerned to identify evidence for (i) the advantages and disadvantages of using the desk-top metaphor in a learning context, (ii) the efficacy or otherwise of the datacube metaphor as a database framework, and (iii) the interaction between the use of these two dissimilar metaphors.

IT applicational tasks

If *Bioview* is to provide a significant learning environment IT applicational tasks should be capable of enhancing cognitive development. Thus the computer intrinsic activities of manipulating the system using the desk-top metaphor and searching the database using the datacube should be applied to complete the task intrinsic activities concerned with learning about photosynthesis. Of particular interest is the use of the datacube metaphor to develop an understanding of science concepts. This research will look for evidence of the use of software features by students to aid their understanding.

A two dimensional research structure emerges from the above analysis. One dimension consists of Birnbaum's task analysis. The other dimension consists of the level of interplay between areas At *level 1* there is no interplay between areas, e.g. a consideration of learning in photosynthesis without reference to general understanding in science; at *level 2* the interplay between areas in the same domain is considered, e.g. the relationship between the desk-top metaphor and the datacube metaphor; and at *level 3* the interplay between areas from different domains is considered, e.g. the relationship between understanding the concepts in photosynthesis and the use of the datacube metaphor. As shown in the Table 1 below this structure gives rise to eight design issues.

	Level 1	Level 2	Level 3
Task intrinsic	(1) Learning about photosynthesis (2) Learning general science concepts and skills	(5) The relationship between photosynthesis concepts and the use of general concepts and skills in science.	
Computer intrinsic	(3) Using the *Windows* graphical user interface (desk-top metaphor) (4) Using the datacube metaphor to explore the database	(6) The simultaneous use of the desk-top and datacube metaphors.	
IT applicational			(7) The use of *Bioview* to develop understanding in photosynthesis (8) The use of *Bioview* to develop the understanding of general concepts and ideas in science

Table 1: Design issues

Norman(1983) introduced distinctions between the user's model of a system, the designer's model and the designer's model of the user's model. In this research the student's model is taken to consist of an amalgam of a student's perception of the graphical user interface (including the datacube metaphor) and the student's current set of science concepts and skills. The designer's model is taken to be an eclectic combination of perceptions and beliefs drawn from a variety of fields, including established theories of photosynthesis, accepted techniques and skills of science, and current theories about the design of effective human computer interfaces. The designer's model of the students model is similarly eclectic, including theories about how students learn science (particularly photosynthesis), perceptions of how students interact with graphical user interfaces, and how students interpret pictorial representations. These distinctions can be applied to the design issues shown in Table 1 as a basis for formulating a set of specific research questions.

Design issue 1: Learning about photosynthesis

There is an extensive body of literature that documents the research into students' understanding of science. This literature includes a number of examples of research into students' understanding of photosynthesis (see Barker and Carr, 1988a; Barker and Carr, 1988b; Eisen and Stavy, 1988; Haslam and Treagust, 1987; Stavy, Eisen and Yaakobi, 1987; Waheed and Lucas, 1992; and Wandersee, 1983). The main thrust of the findings of this research into students' learning in science is that students bring a priori concepts to their studies in science which are typically at variance with accepted concepts in science. It is maintained that good pedagogy should aim to support students in 're-constructing' their own concepts in order to acquire a set of concepts consistent with accepted science.

The designer's model is typically based on the accepted concepts of science, and the student's model will be typically based on one (or more) of the common misconceptions identified in the research literature. The designer's model of the student's model is that students learn by the re-construction of concepts as indicated above. This leads to the following research questions:

Student's model	(i) Do students exhibit the commonly observed misconceptions about photosynthesis?
Designer's model	(i) Does the design of the software assume accepted ideas about photosynthesis?
Designer's model of the student's model	(i) Does the design of the software take account of students re-constructing their concepts associated with photosynthesis? (ii) Is there any attempt to overtly represent students' misconceptions?

Design issue 2: Learning general science concepts and skills

Research into students learning (in science) indicates that they use a variety of approaches to problem solving. Unfortunately not all of these approaches are representative of good practice in science. The designer's model is typically based on the accepted methods in science, and the student's model will be typically based on one (or more) of the common methods adopted by students. The designer's model of the student's model is that students can be encouraged to change their approaches to science, progressively adopting standard methods in science. This leads to the following research questions:

Student's model	(i) Do students employ non-standard scientific methods in using the database to solve problems?
Designer's model	(i) What methods of enquiry does the design of the database enable?
Designer's model of the student's model	(i) Does the design of the software take account of students using idiosyncratic scientific methods?

Design issue 3: Using the Windows graphical user interface (desk-top metaphor)

As *Bioview* is a *Windows* application the designer's model of how the software is manipulated is defined by the features available in this operating system and by the various metaphors that *Windows* uses (notably the desk-top metaphor). The student's model will probably consist of an idiosyncratic sub-set of *Windows* features, which may have been developed through the previous use of other *Windows* applications. The designer's model of the student's model consists of a sub-set of *Windows* features which it is assumed are both necessary and sufficient to manipulate the software. The following research questions arise:

Student's model	(i) What is the sub-set of *Windows* features that students typically employ when using *Bioview*.
Designer's model	Not applicable (*Windows* accepted by default)
Designer's model of the student's model	(i) To what extent do the typical sub-sets of Windows features that students employ match the sub-set of features that the designer assumes to be relevant?

Design issue 4: Using the datacube metaphor to explore the database

The designer's model of the database is based on the datacube metaphor. Using the datacube enables databases representing three interacting variables to be explored. Exploration is effected by a combination of (i) 'slicing' through the datacube to select datasheets representing data arranged in a matrix form corresponding to two variables with the other variable fixed,

(ii) selecting rows (or columns) on a given datasheet, and (iii) looking at the variation in datum values for a given row (or column) by inspecting standard graphical representations, e.g.. a bar chart. It is possible to effect the same exploration of the database by using different combinations of these actions. The student's model will depend on the level of understanding of the datacube representation, whilst the designer's model of the student's model necessarily assumes that a students is capable of using each of the three actions described above, even if they do not appreciate the equivalence of some sequences of actions. Some possible research questions follow:

Student's model	(i) Do students understand the basic operation of the datacube? (ii) Do students use a variety of combinations of datacube actions?
Designer's model	Not applicable (Datacube accepted by default).
Designer's model of the student's model	(i) How valid is the designer's assumption that students can use the datacube metaphor?

Design issue 5: The relationship between photosynthesis concepts and the use of general concepts and skills in science.

The designer's model assumes a relationship between the development of concepts specific to photosynthesis and the use (and development) of scientific methods of enquiry. The student's model may or may not recognise such a link, or the recognition may be tacit. The designer's model of the student's model assumes that students will come to use scientific methods more readily through experience.

Student's model	(i) Do students perceive a relationship between the solution of specific problems in photosynthesis and the use of general scientific methods?
Designer's model	Not applicable (specific-general relationship assumed).

Designer's model of the student's model	(i) How valid is the designer's assumption that students will come to use scientific methods through experience?

Design issue 6: The simultaneous use of the desk-top and datacube metaphors.

The designer's model assumes that the features and associated metaphors available in *Windows* and the datacube are at least compatible, and possibly mutually supportive. In addition it is assumed that graphical animation of the results of datacube actions is desirable, and that it is appropriate to mix screen representations (pictorial, graphical, and tabular). The student's model represents the extent to which these assumptions are legitimate. The designer's model of the student's model is based on the assumption that the an assumed sub-set of *Windows* features is sufficient to resolve possible conflict between metaphors and to provide enough user control to use features of the datacube effectively.

Student's model	(i) Do students experience a conflict between the use of the desk-top metaphor and the datacube metaphor? (ii) What are the most popular combinations of representations?
Designer's model	Not applicable (*Windows* and datacube accepted by default)
Designer's model of the student's model	(i) How adequate is the assumed sub-set of *Windows* in resolving conflict between metaphors? (ii) How adequate is the assumed sub-set of *Windows* in providing students with enough control to use the datacube effectively?

Design issue 7: The use of Bioview to develop understanding in photosynthesis

The designer's model is based on the assumption that the datacube metaphor used within the context of *Bioview* is a legitimate and useful representation of data relating to photosynthesis. The student's model is defined in terms of those features of *Bioview* that they find useful in solving problems concerned with photosynthesis. The designer's model of the student's model is based on the notion that the datacube is a sufficiently flexible and understandable to assist students in developing an understanding of photosynthesis.

Student's model	(i) What features of *Bioview* do students find useful in solving problems in photosynthesis?
Designer's model	Not applicable. (*Windows* and datacube accepted by default)
Designer's model of the student's model	(i) Does the design of *Bioview* take enough account of the features that students find useful in solving problems in photosynthesis?

Design issue 8: The use of Bioview to develop the understanding of general concepts and ideas in science

The designer's model is based on the assumption that the use of the datacube metaphor within the context of *Bioview* makes it possible to represent general science concepts and allow general scientific methods to be employed. The student's model is defined in terms of these general features of the *Bioview* that they find useful in solving problems concerned with photosynthesis. The designer's model of the student's model is based on the notion that the datacube is a sufficiently flexible and understandable to illustrate general science concepts and to allow students to use general scientific methods.

Student's model	(i) What features of *Bioview* do students find useful in applying general scientific methods?
Designer's model	Not applicable
Designer's model of the student's model	(i) Does the design of *Bioview* take enough account of the features that students find useful in applying general scientific methods?

These design issues are summarised in Appendix 1

BIOVIEW AND UNDERSTANDING PHOTOSYNTHESIS

Photosynthesis is a complex topic involving a number of topics and inter-relationships between these topics (Waheed and Lucas, 1992). One aspect of this complexity is the need to investigate multi-variate systems. It is common to think in terms of the relationship between two variables. The capacity of *Bioview* to assist a consideration of three interacting variables implies that it might assist in developing understanding in multi-variate systems.

The research methodology adopted in this study is designed to identify (i) the mental models that students' employ when they use *Bioview* and any subsequent changes in these models, (ii) the designer's mental model of *Bioview*, and (iii) the designer's mental model of the student's mental model. It is intended to analyse data from each of these three perspectives within the context of each of the eight design issues previously identified.

A two phase programme of data collection has been completed. The first phase was concerned with a reflection by teachers (attending a Masters course in educational computing) of the design of *Bioview*. The analysis of data obtained during this phase will be useful in identifying the designer's model and the designer's model of the student's model. This phase features a questionnaire relating to a software evaluation of *Bioview* and a free format group discussion. Additional material for analysis will be provided by the Teachers' and Users' guides for *Bioview* and various handbooks for *Windows* (particularly those relating to user interface design).

The second phase was designed to provide data concerned with students' mental models. During the this phase of the data collection three students were taught by the researcher to (i) manipulate the software, and (ii) to use the software to assist in answering some questions related to the process of photosynthesis which were presented in the form of a worksheet. Each research subject was then paired with a student who had no prior experience of using the software, with the request to teach this student with the aim of answering the questions on the worksheet. The three teaching sessions were video taped and the interviews were audio recorded and transcribed. In addition data was collected through the reflection of research subjects and students on their experiences of using *Bioview* during (i) group discussion by the research subjects after their use of *Bioview* to teach students, and (ii) individual interviews with students taught by the research subjects. The initial teaching session in which the research subjects were introduced by the researcher to *Bioview* and the photosynthesis datacube was also audio taped.

The transcripts corresponding to these sessions will be analysed using the qualitative data analysis techniques developed by Bliss, Monk and Ogborn (1983).

Masters reports submitted by teachers participating in the first phase will also provided data concerned with students' models.

An initial review of the data indicates that the data is not rich with respect to learning about photosynthesis (design issues 1, 5, and 7). However, it appears that further analysis will provide some insights into design issues concerned with user interface design (design issues 3, 4, and 6) and on the use of software to develop general concepts in science design issues 2 and 7).

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APPENDIX 1

Research areas developed by applying Norman's 'distinctions'

Issue	Designer	Student	Designer (Student)
1	'Mature' science	Misconceptions in science	Change: misconceptions to mature science
2	Scientific methods / processes / skills	deviations / alternatives / sub-sets of scientific skills	Change: scientific approaches employed instead of students' own idiosyncratic methods.
3	Desk-top metaphor for software manipulation	Sub-set of desk-top functions (idiosyncratic? - based on experience?)	Defined sub-set of desk-top features as a necessary (and sufficient) requirement
4	'Datacube' metaphor	Level of understanding of the 'datacube' and its possibilities	Use of one or more methods of manipulating a datacube and associated graphical representations
5	Environment sponsors an interaction between specific (photosynthesis) and general science concepts / skills	Application of general techniques to solve specific problems	Change: students will be supported to use the database in ways which reflect a 'mature' approach to science
6	Desk-top metaphor and datacube metaphor are compatible and/or supportive.	Confusion and/or supportive use of metaphors in combination	Assumptions: a defined sub-set of *Windows* is sufficient to resolve possible conflict between metaphors, and provide enough control to use features of datacube effectively
7	Datacube metaphor can represent specific science (photosynthesis) concepts	Specific datacube features which are used to explore photosynthesis	Assumption: datacube is effective in illustrating photosynthesis concepts and providing a medium for the exploration of these concepts
8	Datacube metaphor can represent general science concepts and allow general scientific methods to be employed	Specific datacube features which are used to enable the use of scientific methods of exploration	Assumption: datacube is effective in illustrating general science concepts and in allowing students to develop scientific methods