CHAPTER ELEVEN

Learning Formal Representations through Multimedia

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Introduction

It is a universal feature of academic discourse, no matter what the discipline, that it represents ideas using a particular formalism. Most subjects use a special language, often using everyday words but with specific connotations and precise definitions that are importantly different from the normal meanings. Many subjects also make use of formal representations such as symbolism, notation, diagrams, graphics, and all of these require mastery of their interpretation and implementation for the subject to be properly understood.

It is also a universal characteristic of student learning that students find it difficult to master the interpretation and implementation of formal representations. What heightens the difficulty is that the content of a subject is usually articulated through its formal representational devices, which hinders the student trying to find a toe-hold on which to build a sure-footed route to understanding. The formal representation is meant to act as a vehicle for mediating the teacher's knowledge, whereas in reality it is itself an impediment. A straight-line graph is a beautiful representation of a linear relationship, but it is only interpretable by someone who already understands that a linear relationship concerns the form of the mapping of the domain of one variable onto the domain of another – which gobbledygook is also only interpretable by someone who already understands the concept of a linear relationship. There is a circularity of language and ideas.

The difficulty for the student is that academic knowledge is necessarily mediated through some form of representation – at least a specialist language – and it cannot be experienced directly as most of our knowledge is. Academic knowledge is essentially a second-order phenomenon, the description of someone else's experience of the world (Laurillard, 1993). This is the principal reason for the primacy of discussion as a medium of teaching and learning. Through debate and discussion with the teacher, or at least vicarious experience of it in tutorials, the student can begin to see how the specialist language works, how the discourse proceeds in a particular discipline. The task of learning this 'second language' mirrors all the difficulties of learning a second national language: immersion in the target language is usually the most efficient method.

It is not given to many students to spend their days in research labs, or in conversation with their teachers. Our typical instructional style requires a different approach. If we are to help students gain access to the 'precepts' of a subject we must determine their affordances.

Affordance as an Aspect of Learning Activity

The idea of 'affordance' originated with the psychology of perception. The 'affordances' of an object are what we perceive, and from which we infer its properties. We perceive a dumb-bell made of metallic-painted balsa-wood as heavy because it affords the perception of 'heaviness', although its actual property is 'lightness'. Mostly, affordances do not deceive us of an object's true qualities: thus 'percepts', the content of our perceptions, are reasonably unproblematic.

By contrast, most 'concepts' must be acquired over time: we need to process a series of experiences in order to distil concepts such as 'redness' or 'table manners' or 'length'. The affordances of these concepts concern not just immediate perception, but longer-term analysis and interaction with the environment over time. It would be quite possible for a series of experiences to fail to reveal a particular concept. The sequence and frequency of instances of a concept affect its learnability, which is why primary school curricula must be carefully structured and sequenced to allow students to apprehend the fundamental concepts of the physical environment, such as conservation, equality, etc. The affordances of concepts, therefore, go beyond the immediate perceptual properties, their percepts, and include also the timing of the presentation of instances. Of course the processing of that information is a further stage that must be carried out by the learner, and is independent of the affordances. The sequence and timing may be perfectly optimised, but individuals may approach the processing of that information differently: for example, one study showed that students using a 'focusing' strategy on the instances presented were better able to discern a concept than those using a 'scanning' strategy (Bruner, Goodenough and Austin, 1956).

The term 'concepts' is widely used in the student learning literature, to refer to the theoretical ideas covered in academic study. We talk of the concept of 'force', of a 'vector', of 'short-term-memory' – and of students' conceptual understanding. The term was already being used by psychologists, however, to refer to abstractions from everyday experience. This wide-ranging usage overworks the term. The apprehension of Bruner's 'red circles' is fundamentally different from the apprehension of Newtonian 'force', which is itself very different from the apprehension of the normal meaning of 'force'. In the context of this kind of discussion, the terminology needs to be differentiated more precisely. This is why here, and elsewhere, I have coined the term 'precepts' for academic ideas expressed as theoretical constructs (Laurillard, 1987).

They are 'precepts' because they are defined givens, they cannot be experienced, as percepts can, nor can they be acquired through experience, as concepts can. They are the personal constructs of the scholars in an academic field, whose ideas are the content of academic discourse. 'Precepts' can only be known through formal representation, therefore, such as a specialist language, or some other kind of symbol system. In order to learn and understand these ideas, students can only have access to them through some form of mediation – they cannot be experienced directly because they are someone else's ideas. As I have already argued, the mastery of formal representation is itself problematic for the newcomer to a field of study. The interlinking problems of mastering the formal representation, and mastering the precept to which it provides the only access, make academic study the province of those who can tolerate both complexity and uncertainty. In many areas, of course, the ideas are sufficiently simple, and the formal representations sufficiently transparent that this is a surmountable difficulty. But every subject discipline has some topics which remain opaque and inaccessible for many students, for precisely these reasons. When that is so, how do we best support the student?

The different kinds of affordances I have identified for percepts and concepts will have their parallel also for precepts. If we can establish the affordances of precepts, then we shall begin to see what must be done to help students acquire them. 'Percepts' are directly perceived, and their affordances are those perceptual properties that match the physical properties; 'concepts' are directly experienced, and their affordances combine their perceptual properties and the pattern of their occurrence over time; 'precepts' require interaction with both the content and its representation, and their affordances are therefore the opportunities available to the student to link these two together.

This is expressible in terms of the 'conversational framework' for the academic learning process (Laurillard, 1993). This identifies four kinds of activity for learning to take place: 'discursive' – the discussion between teacher and student, 'interactive' – the task/action/feedback cycle operating in the world of the content, 'adaptation' – of description and task by teacher, and of description and action by student, and 'reflection' – on student performance by the teacher, and on experience by the student. The framework is represented in Figure 11.1. To achieve full understanding of the ideas being put across by the teacher, the student must be able to experience them through interactive operation on the real world, and use reflection on this experience to inform their dialogue with the teacher, and use this dialogue to adapt the way they operate on the world. This dual-level processing is necessary for the student to be able to capture both the content and the representation of the ideas.

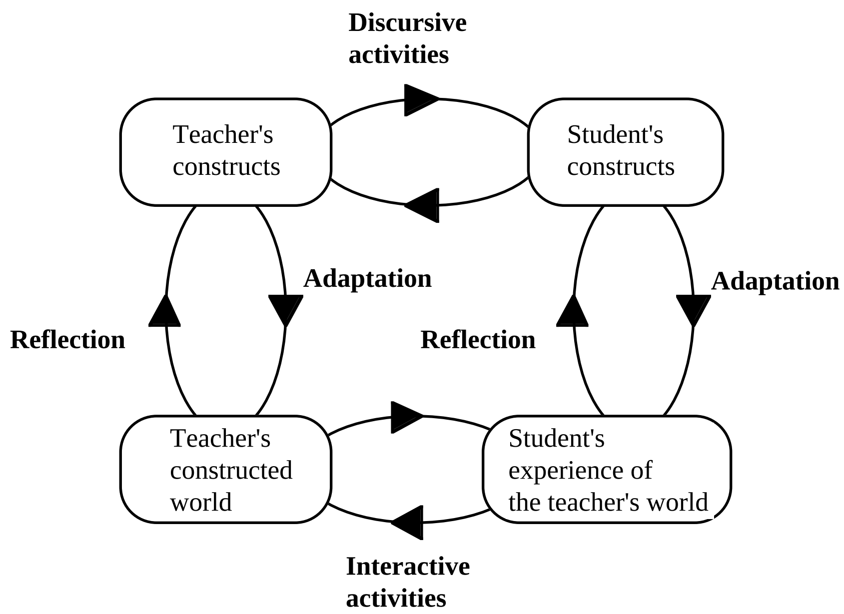
Thus, in borrowing the idea of 'affordance' from the psychology of perception, we can see an analogy with what we must provide in the teaching context if students are to apprehend academic knowledge. The affordances of precepts are quite complex, they involve the combination of all those aspects of the learning process, and if we do not provide for them, we cannot always expect the student to achieve a sound understanding.

The Role of Multimedia in the Provision of Affordances

Traditional teaching methods can support the learning process in the full complexity outlined in Figure 11.1, through a combination of lectures, reading, tutorials, supervised practical work and assessed assignments. Such a combination allows tutor and student to discuss and debate the ideas in the lecture, allows the student to operate on tasks set by the tutor in the practical, and to relate the results of their actions to the theoretical ideas in some form of independent expression – usually an essay – on which they receive further critical feedback. This combination addresses the full conversational framework, which is why these traditions have been established in university teaching. It can work well in the context of small group tutorials and regularly assessed assignments, where the iterative loops in the framework have short time-spans. However, these traditions are being

drastically undermined in universities as numbers increase and resources decrease, and even where the traditions worked well, their effectiveness is now under threat. Large classes and more so-called 'independent learning' address only the input to the student, and not the interaction with the teacher.

FIGURE 11.1
Conversational framework for academic learning



There is no substitute for personal contact with a human tutor, but there are ways in which multimedia technologies can address aspects of the conversational framework that cannot be easily done by other independent learning methods. These are essentially interactive media, incapable of providing genuine discussion with the student, but certainly capable of providing interaction and a degree of adaptive feedback to students on their performance. How well they do this depends on the extent to which the instructional design incorporates the affordances needed for precepts.

This chapter began with reference to a particular instructional problem, namely the problem of the interpretation and implementation of formal representations. This can be used to illustrate the role that multimedia can play in supporting learning if the capabilities of the medium are fully exploited to incorporate the necessary affordances of these particular precepts. The peculiar characteristic of multimedia that is so valuable here, is that it can offer both interaction with a formal system, expressed as a computer model, and a description of that system at any level of sophistication, from the formal to introductory natural language. More than any other medium, therefore, it can address many aspects of the conversational framework, and thereby provide the affordances students need for mastery. Three case studies will serve to illustrate the point.

Case studies of Learning Formal Representations

The three case studies are taken from three different disciplines: earth science, physics, art history. All three use data from studies on student learning which have attempted to document students' misconceptions for a particular topic. In each case, the clear analysis of students' learning needs enables us to derive, almost logically, the instructional design they need.

These cases concern three different kinds of formal representation: geological maps, equations and definitions, and specialist language. In each case, students typically find themselves operating within the formal representation as a vehicle for understanding the content before they have fully understood the representation itself.

(i) Geology

In the case of geological maps, students have to interpret complex maps that represent the geological formations underlying an area of terrain in order to produce a cross-sectional drawing of the formation of the strata beneath. The drawings they produce may be so bizarre that the teacher has great difficulty in knowing how to help them. Students are well aware of their difficulties. They try to use the rules they have been given, but do not understand them:

> This my big problem. I can put marks on the topography, but I can't tell what to do next.
>
> My difficulty is this river – it is going down and then climbing up again... Rivers don't do that.
>
> The way the streams are running gives you the topographic layout, and that's what I'm more familiar with, and I seem to be overly influenced by it.
>
> I have to be careful since sometimes I confuse myself with the dip of the rock and the gradients of the ground. (McCracken and Laurillard, 1994)

These quotes contain the germ of the difficulty. The geological maps in question look very similar to topographical maps, and it is easy for students to interpret the curving boundaries of rock strata as contour lines. Even when that problem is overcome, there is still the difficulty of being able to use a 2-dimensional representation to determine the 4-dimensional story of how the geological events led to this resulting formation. The content is not difficult – the ideas of sedimentation, of folding, faulting and erosion, are not conceptually difficult. But the formal representation of all that information in one 2-dimensional diagram is difficult, and needs special care in its presentation.

(ii) Physics

Newton's Laws of Motion have been extensively researched in an attempt to articulate why students find the idea of force so difficult. It has been studied often in relation to the Second Law, which expresses force as a function of acceleration and mass. Interpretations of situations where the law applies often result in students expressing force as varying with velocity. The mathematical expression may be used in a procedurally correct way, but verbal interpretations may still be incorrect. The normal experience of the use of the word 'force', where it appears to relate to giving some motive impulse to an object, or to define a property of an object, is hard to overcome.

In a study which looked at interpretations of the Third Law, another kind of difficulty emerged. The law, in its simplest form, states that any force has an equal and opposite reaction. Students asked to apply this to an object in free fall reveal another kind of misconception. They believe it concerns equilibrium, and they identify the paired force incorrectly, which makes it difficult to apply the law to this case:

> Air hasn't got the capability to hold something stationary. So there's an unbalanced force down... the force upwards is far less than the force downwards, so it's unbalanced. [Pause]... I'd say that the law does apply but there must be some more to it that I haven't thought of yet.
>
> This case isn't applicable because the body is moving, and it's not constant velocity...Um... you can't sort of say the law only exists for certain bodies... Um...It applies to when they're in equilibrium and at rest, but when the actual system is trying to reach equilibrium, it doesn't' apply.

By identifying the paired force with air resistance, and by trying to find two equal forces acting on the object, the law becomes unintelligible. The correct interpretation emphasises the fact, stated in the original version of the law but not always repeated, that the two forces act on different bodies. The forces that should be paired in this system are 'the earth acting on the object', and 'the object acting on the earth'. By the second law, the very small mass and very large acceleration of the object matches the very large mass and the very small acceleration of the earth. It has nothing to do with equilibrium, which balances forces on a single object.

The combination of mathematical symbolism, static diagrams, and specialist language here creates a formal representation that bears little relation to the student's normal experience of the idea of 'force', and the confusion apparent in these quotes is often maintained over years of study of physics.

(iii) Art History

Students of art history, coming to the subject for the first time, may find that their expectations of the subject are at odds with the way it is taught. Academics see the subject as highly theoretical – "art history is about the made image as a register of broad social, ideological and psychological structures", "art history is an academic discipline conducted like other arts disciplines entirely through reading, writing and verbal discourse" (quoted in Durbridge, 1995). By contrast, students come to the subject because they want to know more about paintings.

> I really don't know where to begin to study a painting. I'd latch onto something striking, like it was very splodgy, or in vivid colours, perhaps... I don't know how to do more than that.. what else to say, or what else matters.
>
> How can people possibly do this stuff until they've learned how to look? What they need is practice.
>
> If there was more enjoyment, a sense of exploration and discovery in the beginning, it might encourage us. [Durbridge, 1995].

There is a striking contrast between what the students expect of the subject and what the academics seek to provide them with. For the students, the immersion in theory and description occurs before they feel properly grounded in the experience of the phenomena being described. As Durbridge points out, the students need to have more experience of looking at paintings, and considering their own reactions to them before they can realistically confront the experts' theoretical constructs. The precepts bear no relation to any concepts, or even percepts, for students who are novices in the study of art. It is like trying to describe geological formations to someone who has never seen a hill. If they have little experience of the phenomena, then students have no access to the affordances of the precepts that describe them. As Durbridge argues, they must be given the chance to 'play' first.

The argument is identical for the two previous case studies as well. Formal representations formalise a way of describing our experience of phenomena, whether the phenomena be objects falling, or the earth moving, or cultural artefacts. Students need access to the affordances of these precepts, and our traditional mode of teaching frequently fails to do this. For many topics this may not matter, as the complexity is not so great that students need additional help. However, as in the examples of the case studies quoted here, there are many topics in higher education that occasion considerable and continuing difficulty for students because the precepts are sufficiently complex, and because we pay sufficiently little attention to providing their affordances.

In the next section the particular role that multimedia can play in providing affordances for academic ideas is illustrated with respect to the three case studies.

Instructional Design in Multimedia

The preceding sections have suggested that the affordances of academic ideas, or precepts, will be given through both interactive experience of the phenomenon, and a correlated discussion of the formal description of that phenomenon. Multimedia, uniquely of any of the teaching media, can offer something close to this. A computer model of the phenomenon can be controlled by the student through parameter manipulation, or commands. This process can simulate experience in the real world, but has the advantage that it is more focused and creates the particular experiences the teacher requires. The same is true of a

laboratory practical, of course, except that a computer model typically behaves more reliably than a practical. The multimedia program can also represent the phenomenon in a variety of ways – iconically, graphically, symbolically, linguistically – and the descriptions given can be under the control of the model, so that the two are indeed correlated.

In addition, the program can interrogate the student for their description of what has been produced. The student may communicate their description in two ways: by selecting from a given set of alternatives, or by typing in their own answer which is then pattern-matched with a pre-defined list of possibilities. It is an imperfect form of communication, but for many purposes may suffice as a reasonable approximation to allowing the student to communicate their idea to the program. It is then possible for the program to compare the student's idea with the pre-defined correct answer and provide feedback either through control of the model, or through pre-programmed text associated with that answer.

With these two levels of processing, the interactive and the discursive, linked by adaptation of the task set, and analysis of the student's performance, the computer-based program can achieve an approximation to coverage of all the affordances necessary for apprehension of certain kinds of precept. Not all precepts could be adequately modelled in a computer program, but when that is possible, then something like this is achievable.

In the three case studies above, we have seen that students need a certain kind of experience before understanding is likely.

(i) Geology

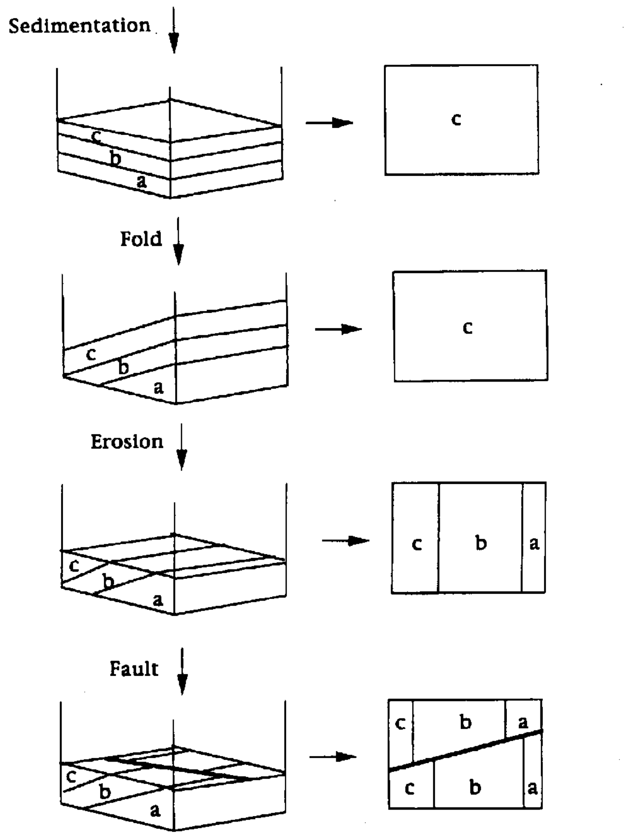
Students in this case study need to see how the experiential relates to the formal in a much more direct way than most media allow. The interpretation of very complex maps is particularly difficult when both the representation and the content are unfamiliar. If students can focus on one aspect to begin with, they can begin to build a surer understanding.

Figure 11.2 shows how an interactive tutorial could provide the affordances students need to make the connection between geological formations and their representation in two-dimensional maps. If students are initially given control over the development of the formation, then they are in a position to know what is being mapped. The program can interpret their commands to generate both an iconic representation of the geology and the corresponding formal representation in the form of a map, since there is a logical relationship.

As students input successive commands to the system, the computer model generates the successive geological forms and their corresponding maps. Student are able to make sense of the link between the two because they know what is being mapped, and because the complex map is built up in stages. Their control of the geological system provides a form of experiential learning, showing the effects of combinations of erosion, sedimentation, folding etc., generating different formations according to the students' input. However, this system does not yet provide the affordances for making the connection between the experiential and the formal – the opportunity is there, but they may not take it. An affordance worthy of the term makes it inevitable that they make the connection. To do that, the program must require of students that they make the connection. One way to do this is to set them a task to find a set of commands that will generate a given map. This requires students to attend to the relationship between the formation they generate, and its formal representation. Similarly, once the generation of the map is understood, it is possible to move to the next stage of asking students to interpret a given map in terms of the successive formations that would have generated it. This is now close to the original task.

FIGURE 11.2
Mapping Geological Formations

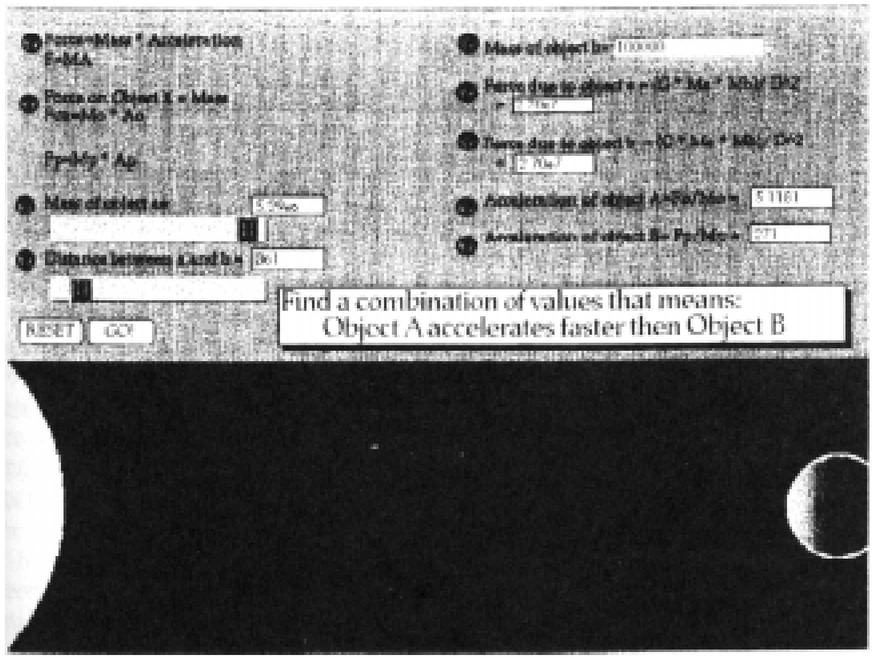
As the student creates the geographical structure through successive geological events, the corresponding map is displayed.



(ii) Physics

In this case, students need to see that the Third Law relates to a two-body system in which the forces acting on the two bodies are equal, no matter what the respective sizes. The force between them is a property of the system, not of a body; it is analogous to a mirror image, which necessarily requires an equal and opposite image. It is difficult to experience the Newtonian idea in the real world because it is idealised and theoretical: you cannot experience the earth accelerating towards a falling object. But in a multimedia world, where the computer models the system and its behaviour, this becomes possible. Figure 11.3 illustrates how a program might construct the control of the two-body system in such a way that it provides the affordances of this precept.

FIGURE 11.3
Computer Representation of a Two-body System in Physics



Students can control the behaviour of object A, by changing its mass. As they do so, the model shows how the objects move, with the two accelerating together if their masses are similar, object A as moving much faster if it is much smaller, and vice versa. Students can therefore experience the phenomenon much more directly than is possible anywhere else, other than an ice-rink, perhaps. Moreover, the program can display the related formal description, showing how the equations in the model determine the resulting force and acceleration, using the parameters input by the student. Buttons on each formal statement expand to an elaborated description of what it means in normal English. Moreover, the student has their attention focused on a specific goal – a combination of parameters that makes the system behave in a certain way – so that they attend to what results from their actions, rather than merely playing. Such an interaction, with the simulated system and with its formal description, gives the student better access to the affordances of this precept than any other medium, apart from the dedicated teacher.

The task-setting in both these cases is an essential aspect of the instructional design because it is this that creates the affordances for making the link between experiential and formal representations. Without it, we provide a mere simulation of the experiential, where students may merely 'see what happens', and not make the vital cognitive link. The task-setting requires that they both reflect on the representation of the interaction with the model, and adapt their actions in that model in the light of what the formal representation tells them. Thus both levels of the conversational framework are served, together with the reflective and adaptive links between them.

(iii) Art history

In this case study the formal representation being targeted is language – the specialist language of the academic. The expert writes about paintings in terms such as 'genre', 'period', 'tonality', etc., but what experience of paintings can students bring to the interpretation and application of this language? They have very little to draw on. They need to begin by extending their experience, and generating their own language with which to confront the experts.

FIGURE 11.4
Multimedia program to allow individual categorising of paintings

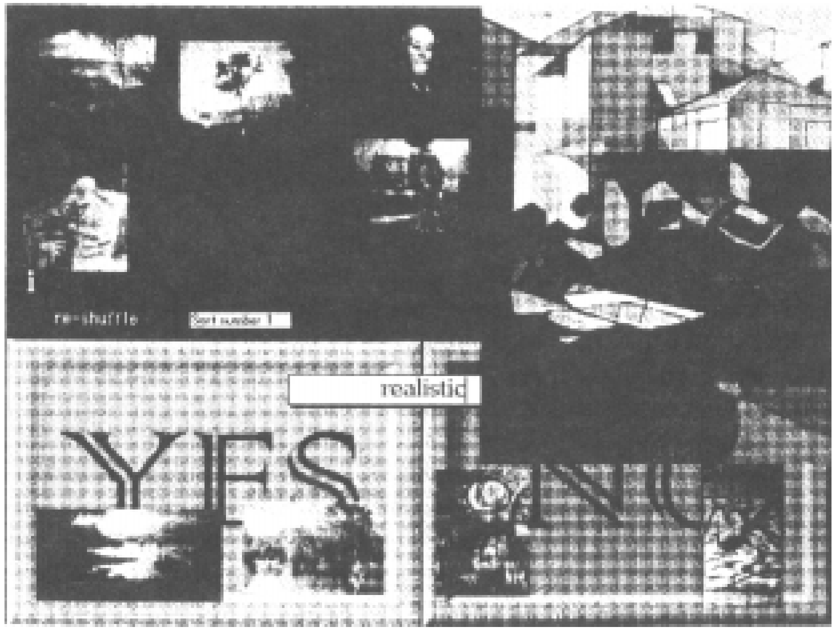


Figure 11.4 shows how this was done in a design followed through from the original research with students (Durbridge, 1995). Students can examine some 20 paintings in close-up, and decide how they would like to sort them.

In a task similar to construct elicitation techniques, the program invites students first to generate their own categories, then sort the paintings according to those which fit a category and those which do not (e.g. the category 'lots of sky'). They are also asked to generate a category that will discriminate between two given paintings. Thus they begin to look closely at paintings in a way that helps to develop their own language of description. At later stages they are shown which of their categories produce similar 'sorts', so that they can gradually refine their use of language as they develop their own descriptive system. Once this is established, they are then shown how others have sorted the paintings, both students and experts, and again they can refine their own categories.

Stand-alone multimedia systems cannot set up a debate and discussion between student and tutor, but this design comes very close to enabling students to establish their own linguistic constructs and then test these against those of the expert. The task set requires them to look closely at the paintings, in a variety of combinations, and to reflect on their own categorisations, compare them with others', and adapt accordingly. The program affords practice in the interpretation and application of the expert's constructs. When the students now confront precepts concerning the evidence of 'tonality' or 'texture' of a painting, they have some experiences and formal descriptions of their own against which to test these new ideas. They have some ground on which to build. And once again, the nature of the task set is the key to providing the affordances they need.

Concluding points

In all three case studies, I have tried to show that (a) students have considerable conceptual difficulties in mastering precepts given through formal representations of experiential phenomena, especially when the phenomena are scarcely experienced by students, and the formal representation is complex; and (b) interactive multimedia programs can provide the affordances they need for understanding such precepts because they can combine so many aspects of the conversational framework necessary for academic learning.

Instructional design should proceed from a detailed understanding of students' needs, especially for the traditionally difficult topics in a subject. A needs analysis will not always lead to a requirement for interactive multimedia, but where a topic requires that kind of extensive support, then we must also attend to the construction of the affordances for understanding the topic, making full use of the characteristics the medium can offer.