THE SCIENCE OF EFFECTIVE COMMUNICATION IN PHYSICS

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1 INTRODUCTION

Physics education research (PER) has shown that the traditional lecture does not promote conceptual understanding [1-4]. Yet in the UK the lecture still forms the core teaching activity in most universities, and is likely to do so for the foreseeable future, despite changes to the school curriculum and an increasingly diverse student intake. Both PER and cognitive models of learning [5] have shown that students need to be active to learn, but in a lecture students are largely passive spectators. Moreover, their own hidden beliefs, preconceptions, and conceptual filtering can actually impede their learning [6,7].

The are two essential difficulties with lecturing as a method of instruction. First, the onus is very much on the student to work with the information delivered in the lecture for meaningful learning to occur, and second, because the onus is on the student, material must be delivered in a way that can be understood intellectually. The first of these can be overcome by careful design of material to be taught [5], especially assessments, but the second is essentially a problem in communication. In this paper communication is addressed through a fusion of cognitive models and thinking styles and a very simple test of the immediate impact of a lecture was designed.

2 A MODEL OF COMMUNICATION

In a previous EPEC conference [8] the author put forward the idea that Biggs' model of SOLO [5,9] (structure of observed learning outcomes) together with Herrmann's quadrant thinking model [10] led to a better model of learning which is probably general but is especially suited to physics in so far as it agrees with, and supports, the various findings of PER. However, it goes further: PER provides no clue as to how to improve lectures, whereas a cognitive model can identify aspects of the structure of a lecture that affect communication.

SOLO is a cognitive model of learning based on the idea that cognitive structure is hypothetical and essentially unmeasurable. Learning has to occur before any testing can be done so what is being measured, therefore, are learning outcomes. Biggs assigned five levels to these; pre-structural, uni-structural, multi-structural, relational, and extended abstract. Pre-structural is the lowest level and indicates that little or no learning has occurred. In a uni-structural outcome the learner concentrates on a single concept or fact and in a multi-structural outcome several unrelated ideas are learnt. These ideas might, in themselves, be related but whether learner perceives them as separate or not determines the outcome. If the

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learner has begun to relate different ideas the outcome is relational, and if new knowledge and understanding is generated from the given the outcome is extended abstract.

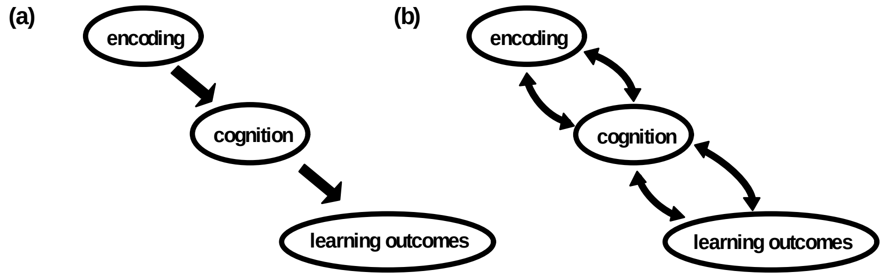

Figure 1 Biggs' sequential model of learning (a), and a more realistic representation of the complex interplay between different stages (b).

The SOLO representation of the learning process is sequential (Figure 1a). Information is taken in (encoded), processed (cognition) and then outcomes are demonstrated. The essential difficulty with this model is the hierarchical nature of the terminology. Biggs used the same terms to describe both the input and the output on the basis that there is no direct relationship between the two. Information may be encoded at different levels, depending on motivation and interest, and outcomes demonstrated at entirely different levels depending on the amount of processing occurring in between. True learning probably does not occur in this simplified sequential fashion, but is more likely a complex cycle wherein input, cognition and output are constantly revisited in the light of feedback, uncertainty, contradictions and misunderstandings (Figure 1b). Nonetheless, as a general statement about what happens in a particular situation Biggs' model is effective. Applied to a lecture, students will encode and process information, but would probably not normally demonstrate learning outcomes. Were they to do so, the outcomes might be expected to be at a low level as students might well be thinking about, and trying to understand, the material, but there simply isn't time in a lecture to think deeply about it.

A further weakness in SOLO is that it doesn't allow for development in the subject. Biggs identified interest and motivation as the principal factors affecting the level at which information is taken in, but in fact it is more complicated than this. Elby has shown [11] that students' epistemological views about physics influence the way they approach the subject and therefore how they learn it. Those who see physics as a set of facts to be learnt and memorized will not begin to relate ideas together until their views about physics permit them to do so. This has nothing to do with interest or motivation but is characteristic of a way of thinking and suggests that as students develop in the subject their way of learning could change. Biggs hierarchical structure cannot account for this. Moreover, a hierarchical input structure is inevitably going to be associated with ability and will therefore be pejorative and to the disadvantage of the student. The answer to this difficulty lies in replacing the SOLO structure at input with thinking styles.

There are many models of thinking styles in the literature and quite possibly all of them will apply to some extent, but the model favoured here is Herrmann's quadrant thinking model [10]. This is a metaphor based on the left/right, higher order/lower order split in the brain and has been used very successfully to improve communication within business. Importantly, Herrmann has characterised the typical thinking patterns from a number of different professions and shown how characteristic patterns emerge [10]. In particular he has shown the development in thinking styles that occurs in engineers between entering university and becoming professional practitioners. Given Elby's findings, this sort of characterisation is very important.

A particularly useful feature of Herrmann's model is the close correspondence between the thinking styles he uses and some of the levels in the SOLO hierarchy (Figure 2). Herrmann identified four styles, which he labelled A, B, C, and D, corresponding respectively to analytical, organisational, emotional, and conceptual. A, B and D correspond roughly to multi-structural, uni-structural, and relational, though there is some overlap (Figure 2). Extended abstract is probably a combination of all four thinking styles, though it is also clearly related to the conceptual style of thinking. Therefore the SOLO hierarchy can be replaced as a description of the input by the quadrant thinking styles. Moreover, quadrant thinking, as illustrated on the right of Figure 3, is very closely related to the epistemological views described by Elby, so whereas SOLO tells us *how* students might perceive a lecture, thinking styles can tell us *why* they perceive it thus and why they learn physics in the way that they do.

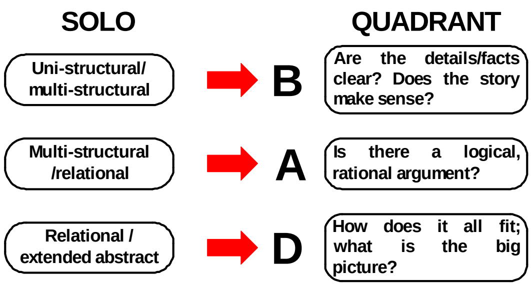

Figure 2 The correspondence between the SOLO hierarchy and quadrant thinking.

Figure 2 also provides a template for communication in a lecture. Students who naturally think in quadrant D will attempt to relate new ideas to known information, but this is also a fairly high order cognitive skill that will probably not be exercised by the majority of students. A lecture designed to relate concepts to each other is likely to be understood only by a minority of students who will, in all likelihood, establish these relations in their own studies outside the lecture. In order to appeal to a majority of students a lecture should be principally uni-structural or multi-structural and deal with a limited number of ideas. According to Herrmann, however, such a lecture will also appeal to thinking styles A and B, and possibly to D.

In order to test how well communication occurred the learning outcomes were tested by giving the students a questionnaire at the end of each of a series of lectures on second year undergraduate solid state physics and final year statistical mechanics. The questions were intended to probe directly the outcome of the lecture according to the SOLO categories and consisted of the following:

- What single fact/idea stands out?
- What other ideas can you identify as important?
- Can you relate these ideas to other knowledge?

3 RESULTS

Several findings emerged from the analysis of the questionnaires.

- Students rarely focus on the idea the lecturer intends they should focus on, even if told repeatedly during a lecture that a particular concept is important and should be remembered. In a lecture on the Drude model of electronic conduction, for example, students were told several times that the most important idea in the lecture was the mean free time between collisions. Not one student recalled this at the end of the lecture and instead focussed on other ideas in the model.
- As in the above, a range of “single most important” ideas/facts is returned from even a conventionally “well-structured” lecture in which the previous lecture is summarized, the subject is introduced, not too many new ideas are introduced, and the lecture is summarized at the end.
- Students often are not able to identify many other facts/ideas. It seems that students focus on one concept and concentrate on this.
- The lecture material is often not related to other knowledge. Even when it is known that other, related material has been covered elsewhere students often do not appear able to relate material just taught to these concepts. When such relating does occur, it is the main to one other concept only.

It would appear from the above that the learning outcome from a lecture is predominantly uni-structural, even at third year level. Possibly higher order learning outcomes are only demonstrated after cognition outside the lecture, but the present work did not test for this. Communication seemed to occur best when only one new concept was introduced during a lecture, all others have previously been met by students. Under these circumstances nearly all students recall this same idea as being the most important. It would appear that if more than one new concept is introduced students concentrate on one at the expense of the others. This underlines the importance of effective note-taking; at least then students will have a record of the other ideas and by writing up the notes will be able to learn those that are not retained.

This simple survey also revealed several examples of miscommunication:

1. In a lecture on semiconductor devices, Poisson's equation was used to derive the voltage across a depletion region. The students should have known about divergence, but in fact were not too familiar with the idea. The end of the lecture turned into a tutorial on the vector operators *div* and *grad*, but these then became the focus of the students' attention rather than the application of the vector calculus to depletion regions.
2. There are several ways of introducing band structure; bands of forbidden energy arise from electron diffraction in a periodic lattice or the bands themselves arise from overlapping electron wavefunctions. These can be considered as different perspectives on the same issue, but they are also very different ideas. Both were introduced as new material within the same lecture, but as with the above students did not know which idea to focus on.

4 CONCLUSION

The problem of communication identified in this paper is essentially unrecognised. It will be widely accepted that a well-structured lecture should not contain too many new ideas. According to Miller [12] the average working memory can handle 7 "chunks" of information. This might lead one to expect that if two, three, or even four new ideas are introduced the working memory should still be able to cope. Instead it seems that a single new concept supported by other ideas that have already been met is best, even at a fairly advanced level. Surprising though this might seem at first sight, it is nonetheless consistent with working memory as a limiting factor. Knowledge which has been internalised can be incorporated into what Miller called "chunks", thereby reducing the load on working memory, but if concepts introduced in previous lectures have not been learnt they cannot be combined into chunks. Reintroducing them into another lecture loads the working memory and leaves little room for new ideas.

One of the interesting observations to arise from this work is the essential unpredictability of what it is that students will focus on and take from the lecture. In order to ensure that attention remains fixed on an intended outcome the central idea must be approached from a number of different perspectives. Using multiple perspectives and representations, such as graphs, diagrams, equations, etc. is one of the ways that PER has identified as improving learning. Quite possibly the different perspectives address different thinking styles, but the one effect is to limit the amount of new information that students receive. This brings the students back to the central idea and reinforces the concept.

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