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AUTHOR White, Richard T.

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ABSTRACT

This document presents the rationale for laboratory work, which is alleged to be ritualistic in many schools and colleges. The rationale is that laboratories are a fertile source of memory structures called episodes, which would enhance the comprehension of abstract subject matter when associated with it. Specific and generalized episodes are described. Consideration of these episodes leads to recommendations for inclusion in a year's program of: (1) a few unusual and dramatic experiments that can be linked to topics of central importance; (2) experiments that involve common, everyday objects as equipment so that physics can be more easily related to daily life; and (3) experiments that are true problems, which will train students in planning an investigation instead of following directions and in writing a proper report instead of reciting the steps laid down in a manual. (Author/GA)

RELEVANCE OF PRACTICAL WORK TO COMPREHENSION OF PHYSICS

RICHARD T. WHITE

MONASH UNIVERSITY

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Relevance of Practical Work to Comprehension of Physics

Richard T. White,
Monash University,
Clayton, Victoria,
AUSTRALIA, 3168.

ABSTRACT

An explicit rationale is presented for laboratory work, which is alleged to be ritualistic in many schools and colleges. The rationale is that laboratories are a fertile source of memory structures called episodes, which should enhance the comprehension of abstract subject matter when associated with it. Specific and generalized episodes are described. Consideration of these episodes leads to recommendations for inclusion in a year's program of (a) a few unusual and dramatic experiments that can be linked to topics of central importance; (b) experiments that involve common, everyday objects as equipment so that physics can lose some of its "labness" and be more easily related to daily life; and (c) experiments that are true problems, which will train students in planning an investigation instead of following directions and in writing a proper report instead of reciting the steps laid down in a manual.

RELEVANCE OF PRACTICAL WORK TO COMPREHENSION OF PHYSICS

One of my older American friends tells me that before the Second World War he took a university course named Gentlemen's Physics. This was not, as one might now suppose, an alternative to Ladies' Physics, but to a course that covered the same subject matter and also included practical work in the laboratory. Named simply Physics, this must have been intended for the lower classes of society.

Courses such as Gentlemen's Physics are now non-existent or rare, despite the obvious economy of having no practical work. Their disappearance is not a result of research evidence, since those few studies which have investigated laboratory work in the sciences have found it produced little difference except in manipulative skills (e.g., Kruglak, 1953; Yager, Engen, & Snider, 1969). Rather there seems to be a settled faith in the value of practical work, a near-religion to which we are prepared to donate large amounts of time and money. One consequence of the dogmatic foundation of practical work is that only too often it becomes a matter of ritual, the purpose of which is lost. Then practical work is included in courses because it is expected, not for a particular reason. Hence any exercise is seen as being as good as any other. Nor is there any way of judging whether the set of exercises in a course is complete enough; no way of telling whether a particular type of exercise is lacking; and no way of judging whether the exercises in a course are fulfilling any purpose. Therefore it should be useful to inspect the basis of the faith in practical work, since this might establish it on a firmer, more rational ground than that of accepted dogma, and we might then be led to new and more effective forms of laboratory exercises.

Types of Performance and Elements of Memory

Practical work is intended to enhance subsequent performance. Since performance is a comprehensive term, we may need to look more closely at what we mean by it. A useful initial split is into cognitive, affective, and motor outcomes. We will concentrate on the cognitive domain because of its importance and because laboratory exercises already seem effective in training learners in motor skills, and the affective domain is too complex to tackle. Cognitive performances can be divided further along two distinct dimensions, one concerning the type of subject matter that is involved, and the other the degree of novelty in the performance, that is whether it is just straight recall of a piece of knowledge or whether some transfer of knowledge is necessary. In discussing these two dimensions we will find it convenient not to treat the learner as a black box but to use a description of memory processes and their involvement in performance. Then we can consider improvements in the current conduct of laboratory work.

The most useful division of subject matter for our purpose is that made by Gagné (1968) between verbal knowledge and intellectual skills. The former are single facts while the latter are capacities to perform a whole class of tasks. Learning that the Weber is a unit of magnetic flux is acquiring a piece of verbal knowledge, while learning to solve two-dimensional collision problems by the application of the principle of conservation of momentum is acquiring an intellectual skill. In the first instance the knowledge can be expressed in effectively only a single way, while in the second an algorithm is involved which will allow solution of an infinite number of examples. This division is important because there are quite different procedures involved in learning the two types. Verbal knowledge is readily acquired, given a knowledge of the language involved. We can teach anyone with a command of English that, for example, diamond has a high refractive index. Whether they comprehend the full meaning of the statement or not is another matter, but as far as the acquisition of this fact is concerned, for most people a single statement of it by the instructor will be enough. Intellectual skills are not so easily acquired. Gagné, Mayor, Garstens, and Paradise (1962) and White (1974), among others, have shown that they are learned hierarchically in that the skill cannot be learned unless all of a set of identifiable pre-requisite skills are already possessed.

Both verbal knowledge and intellectual skills are stored away as elements of long-term knowledge. Where they are not associated by the learner with any other element we say they have been learned by rote, and that understanding is a consequence of linking the elements with others in memory. Gagné and White (1978) have elaborated this notion, and in addition have identified two further elements of long term memory which they call images and episodes. These too may influence the storage of facts or skills by being linked with them. Images are figural representations in memory of diagrams, pictures, or scenes. Episodes are representations stored in memory of past events in which the individual was personally involved, either as an active protagonist or as an observer. Since episodes are an important part of the theme of this paper, some further description of them is necessary.

Episodes

We can conceive of a continuum of episodes which runs from specific to general ones. Although the following discussion necessarily treats them as a dichotomy, the notion of a continuum should not be forgotten.

Let us consider specific episodes first. Each of us has an idiosyncratic set of specific episodes, which go on being formed and stored at all ages beyond earliest infancy. One of mine, for example, is of sitting in a launch in a featureless sea from which, through falling of the tide, the Great Barrier Reef suddenly rose up, at first as isolated blocks of coral and then as a low wall stretching to left and right as far as I could see. Quite specific details remain to me of this recollection of an event a quarter of a century old: my position in the launch and its orientation to the reef, the feel of a slight ocean swell, the presence of fishing lines trolling behind. In this instance I was a passive observer, but in another I was an active participant. This was in the first year Physics laboratory at the University of Melbourne, when in doing an experiment concerning viscosity I allowed oil to spill over myself and the floor. These examples illustrate why some events are more recallable than others: the ones we find easiest to recall are those that are unusual in some manner that engages the emotions. They are often dramatic. The emotions involved may be of any type, such as pleasure and a sense of wonder, grandeur and beauty as in the example of the Reef, or surprise, annoyance, and embarrassment as with the oil.

Specific episodes are powerful aids to recall of any knowledge that is associated with them. I remember, for instance, seeing a demonstration of carbon monoxide being ignited in a two metre tall gas jar. The gas burnt slowly down with a paraboloid flame, emitting blue light and a musical note which rose in pitch as the flame neared the bottom of the jar. This memorable event is associated for me with verbal knowledge about energy transformations and the properties of carbon monoxide, and in fact is a link for me between two topics which otherwise would not be closely associated in my memory. Hence that specific episode is a strong peg which maintains for me the easy recallability of the associated verbal knowledge.

At the other end of the continuum from highly specific episodes are generalised ones. These are attracting some attention in psychology. In the terminology of Schank and Abelson (1977) they are known as scripts. They are formed from repeated experiences which we perceive as being of the same type. When we have the same sort of experience many times we abstract from it its general features, and when we are cued by the name we have given to that experience we can construct in our minds representations of it. When you contemplate the cue "bicycle", you can (if you have ridden one) recapture the feeling of being on a bicycle and may even be able to picture yourself riding along on one. This does not prohibit recall of a specific episode involving a bicycle; you can recall both generalised and specific episodes more or less at the same time.

Generalised episodes, though not formed on the dramatic and emotive basis of specific ones, are also important in the learning and subsequent recall and transfer of subject matter. They provide a stock of concrete experiences which are essential in giving meaning to new information. When people are being told something new about bicycles, or electrical circuits or energy or electrons, they will comprehend the information and assimilate it better if they have a stock of generalised episodes about these topics. Notions such as entropy or case grammar or gross national product are hard to comprehend because we cannot easily make them concrete or attach them to any past experience. Inability to relate new information to generalised episodes either directly or through a short chain of other knowledge means that it is learned in an abstract fashion, so that there is a tendency to lose the ability to recall it and it is difficult to apply it. As Mayer and Greeno (1972) have shown, absence of such contacts, which they call external connecti inhibits performance in solving problems.

Episodes and the Laboratory

Now let us consider the physics laboratory in the light of these notions of specific and generalised episodes.

Specific episodes

Laboratories currently are in the main smoothly organised places where the unexpected is not intended to occur. Dramatic, emotive events are rare, and so strong specific episodes are unlikely to be formed. Where they are, it will often be through some disaster such as my example of spilling the oil, and as it is the nature of these events to occur in a random, uncontrolled and unpredictable fashion they are unlikely to be linked with subject matter in a useful way. But since specific episodes are powerful aids to recall, as illustrated by my example of burning carbon monoxide, we might profit from altering present laboratory practice so that controlled episodes are more likely to be formed. We cannot have all experiments dramatic, emotive, or unusual. Apart from the difficulty of inventing a large number of such experiments, the fact of having many would militate against their unusualness. In a year's course we can have only a handful of experiments that are so unusual that doing them will establish permanent specific episodes. Therefore the topics for these experiments should be chosen carefully, and should be key topics of the course rather than fringe ones. In secondary school physics, for example, conservation of energy may be agreed upon as a central topic, so a spectacular energy change experiment would be good to have. An example would be for students to make a powerful catapult, to construct its force-extension graph so enabling them to calculate the work done in extending it, and then to use it outside firing a known mass at 45° when the range can be used to find the kinetic energy at the moment of release. There is a lot of physics in such an experiment, but its main value is its novelty, which will make it memorable.

More is needed than simply the experiments themselves. Early results of some work in progress by Elaine Atkinson at Monash University Faculty of Education suggest that students often fail to connect practical work with other subject matter, so in addition to providing suitably unusual experiments which will establish episodes in students' minds, teachers will have to consider how to encourage them to link the episode with appropriate intellectual skills and verbal knowledge. At present this is either left to chance or is assumed to be an automatic process. It is not yet known how such links can be produced, but a simple technique might be sufficient, such as emphasising a sentence in which a good descriptive name of the experiment is combined with the name of the physical principle. For our example this might be "This catapult experiment is about transformation of energy."

Generalised episodes

What purpose is served by the present form of laboratory experience, which does not reach dramatic heights? From the earlier discussion we can see that such experiments do provide a stock of generalised episodes which should be important in the learning of physics. These generalised episodes come from repetitive and varied meetings with pervasive concepts such as measurement and accuracy and with measured quantities such as length, time, potential difference, or current, and from direct experience of phenomena such as refraction. The experiments, the handling of apparatus, provide a concreteness or shift from abstraction which "Gentlemen's Physics" lacks. This shift is good because generalised episodes act as readily recalled posts to which new information can be linked and thus made more comprehensible, and because they aid recall of information about specific quantities such as potential difference. Recall of verbal knowledge and intellectual skills is not a simple matter but is a function of the mass of elements of long term memory that are associated with them. The greater the set of associated episodes and images the more readily will the knowledge be recalled. In this context we should note that laboratory work, as well as leading to episodes, may provide a much greater range of images than will generally be the case for non-laboratory instruction, especially if we do not restrict the term to visual images but also include tactile ones.

Does this notion of generalised episc indicate any shortcomings in the current organization of laboratory wor. The usual form of laboratory exercise does give experiences of measurements and meetings with physical quantities, and the repetition of these experiments does lead to useful generalised episodes. The weakness of these episodes lies in their "labness", their lack of relation to events of daily life outside the school or university. If they did so relate, the daily life experiences would help the formation of the episodes and speed the process of abstracting their important general features, and the episodes would be a much-needed link between the school and daily life. The implication is that a substantial proportion of laboratory experiments needs to be taken out of the laboratory and away from artificial apparatus, and should be carried out in a daily life context with familiar materials. Of course this is diffficult, and not possible for all topics. However, mechanics, optics, and electricity surely contain many opportunities to make this change. Kinematics experiments, for example, might better be done with people, bicycles, and cars than solely with trolleys and airtracks; experiments on refraction might involve swimming pools rather than glass blocks; and electricity might better be studied with house fuses, switches, and meters or with torches (flashlights) in their commercial cases than with rheostats and potentiometers. As well as providing more recallable and useful generalised episodes these changes could make students see physics as a more relevant study in their lives than they do now.

Integration of Knowledge

The notion of linking episodes to other knowledge enables us to identify one further type of experiment which currently is missing from our laboratories. Once learned, knowledge can be further integrated by increasing and strengthening the links between its elements. This can be brought about by applying the knowledge in solving problems: the act of doing the problems forces new connections to be made. Pencil and paper problems are not powerful enough to be fully effective in this regard, but practical situations are excellent. They can force students to integrate knowledge in solving real problems. Unfortunately, hardly any experiments in school or undergraduate physics today are presented to students as problems; rather they are exercises in following directions. An example of a real problem would be to give a student an inflated balloon with the request to measure the potential energy stored in it, and with no further instructions on how to go about it. White (1976) lists a few more examples of practical problems of this type.

Experiments that are true problems train students for two desirable outcomes which have not yet been touched on. One is the ability to design experiments, that is to list the sequence of actions necessary once a general course has been specified. The present direction-following experiments do nothing for this outcome. The other is the ability to describe the experiment. The current laboratory report is too often a stereotyped repetition of the instructions, which does not teach the student how to organize his writing nor how to describe actions in a way that will be useful outside the laboratory. This is a pity, since the science laboratory is one of the few parts of the curriculum where students can practise writing a specific, detailed description of actions and reasons for them, or of hypotheses for things seen. In this respect stereotyped laboratory reports are letting down the whole curriculum, not just the subject of Physics.

Summary

It is suggested that three types of experiment be added to those normally used in physics courses. One type is the unusual experiment which engages the emotions through being odd, dramatic, beautiful, or puzzling. A few of these experiments in a year's course should be used as powerful aids to the recall of the most important topics. Another type is intended to establish generalised episodes involving materials and events of common experience, with the purposes of linking school subject matter and daily life and of providing experiences which will be called into play in making subsequent information comprehensible. The third type consists of true problem solving exercises which serve to integrate students' knowledge of physics, making that knowledge more readily recallable and applicable to further problems. In addition these exercises will train the students in designing experiments and in writing reports.

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