

Intellectual Development and Performance in Undergraduate Physics

P.J. Jennings and M.G. Zadnik*

School of Mathematical and Physical Sciences, Murdoch University, Murdoch, W.A. 6150.

In this article we examine the intellectual development of a class of first year physics students at Murdoch University at the beginning of their course and attempt to relate their cognitive level to their performance in this physics course. We also assess the relationship between cognitive level and the difficulty students had in assimilating the course material.

Background

There has been considerable interest in the application of educational theories of Jean Piaget to the learning of physics (Renner and Lawson, 1973; Fuller, 1982). According to Piaget and Inhelder (1958) children pass through four stages of intellectual development — “sensory-motor”, “pre-operational”, “concrete-operational” and “formal-operational”. By the time they leave high school many should have entered the final, “formal-operational” stage (Karplus, 1977). At this stage they are supposed to be capable of formal, abstract scientific thinking while in the previous “concrete-operational” stage they are incapable of using abstract logic. Students at a concrete-operational stage of development are capable of understanding and using science but this is only via analogy from concrete examples or demonstrations or experiments which they have witnessed. At the formal-operational stage students are able to manipulate abstract concepts with no need to resort to concrete objects in the process. Many students exhibit characteristics of both of these stages during their first years of tertiary study. Such students are described as transitional.

Many science educators have drawn on these theories and developed courses which provide both concrete and formal elements to cater to students at various stages of their intellectual development. Their aim is to provide the basic concrete experience in science upon which students may build formal abstractions and thus foster intellectual development (Fuller, 1982). Many of these ideas are familiar to physics educators who have long used lecture demonstrations and laboratory sessions to provide direct concrete experience of physical phenomena to students. The most significant of these developments is the Karplus Learning Cycle (Lawson and Renner, 1975) in which concrete learning experiences become a central part of the teaching method. Karplus (1977) recommends that a course should be broken down into a large number of modules and that each module should be studied via a three-stage learning cycle based on the theories of Piaget. The first stage is called *exploration* and is devoted to practical activities and demonstrations through which the students can progress at their own pace. The second stage is called *concept introduction* in which formal reasoning methods are introduced by means of lectures, tapes or notes drawing upon the exploration activities in the previous stage. The final stage is *concept application* in which the students apply the new concepts or reasoning patterns to unfamiliar examples or to experiments. Thus the students progress from one module to the next in this manner, building up formal

reasoning patterns on a basis of concrete experience.

Piaget's ideas and Karplus' application of them to learning in the sciences have many supporters and some critics. The University of Nebraska has developed a physics programme based on these principles (Fuller, 1982) and many other courses have been modified to include elements of the Karplus Learning Cycle. We have had considerable success with an introductory computer programming course based on a book by Peckham (1981) which uses the Karplus Learning Cycle (Jennings and Atkinson, 1982).

Cognitive testing programmes in the USA (Renner and Lawson, 1973; Liberman and Hudson, 1979) indicate that many university entrants have not fully reached the formal-operational stage of intellectual development. This does not mean that they are still concrete-operational thinkers. Most are at a transitional stage where they still have difficulty with abstract thought processes when they first enter university. Consequently the supporters of Piaget's theories advocate the use of practical experience as an aid to the development of abstract thought processes for all university entrants (Prigo, 1977). They emphasize that self-regulation is essential in the learning cycle and that learning is most effective when a sound basis for it has been established through practical experience and discussion of concepts and their application.

The critics of this approach (Orear, 1980; Goodwin, 1978) point out that Piaget's theories have been oversimplified in these applications. Further they claim that there is no clear distinction between the different stages of development which Piaget has identified. It could also be argued that concrete models and thinking by analogy are important even at advanced levels in physics and that formal-operational thinking is not essential for success in physics. Some authors point to a lack of correlation between intellectual development and success in physics (Cohen *et al*, 1978; Liberman and Hudson, 1979) to support their views that Piaget's ideas have very little real relevance for physics education.

In this article we attempt to assess the validity of some of these claims in the context of our first year mechanics course at Murdoch University.

Cognitive Testing

Piaget's original experiments were carried out by analysing individual children's attempts to solve practical problems. This case-studies approach is however quite unsuitable for application to large classes of students and many subsequent researchers in this field have developed written diagnostic tests which may be used to determine intellectual development (e.g. Liberman and Hudson, 1979; *et al*, 1978). Most of these tests contain problems related to the specific tasks which Piaget identified as being useful indicators of cognitive level. These include simple proportion, combinations of variables, isolation of variables, verbal analogies, correlations, verbal and numerical abstractions, probability estimates. Generally the student is asked to solve a problem and display his or her reasoning. The marker assesses both the correctness of the answer and the method by which it was attained in order to determine the student's cognitive level. Concrete

* Present address: Enrico Fermi Institute, University of Chicago, Chicago, Illinois, 60637, U.S.A.

thinkers tend to work via concrete analogies, explicitly examining all particular cases while formal thinkers are able to work in abstract, general terms. Usually one finds in marking these tests that most students of physics use a combination of formal and concrete reasoning and many are able to switch easily from one mode to the other to find the most effective method of solving the problem. Indeed by its practical nature, physics is a field in which both forms of reasoning are encouraged and developed.

After several years of experimentation and interviews and analysis of student responses we have developed our own version of the cognitive test which we find simple to administer and relatively straightforward to mark. It contains five of the Piagetian tasks: simple proportion, verbal analogies, combinations of variables, isolation of variables, and verbal and numerical abstractions. Three of the questions require written answers and explanations and the other two require only multiple choice selections. Copies of the test and marking scheme are available from the authors.

The written answers were marked independently by two markers using a marking scheme based on a Piagetian analysis. Differences were resolved by discussion between the markers.

We administered this test to a group of 48 students at the start of their first year mechanics course at Murdoch University. These students were predominantly science majors who had had some exposure to physics and calculus during their high school studies. This course is run on a modified version of the Keller scheme (Keller, 1968) which allows students to study at their own pace (Cornish and Jennings, 1977). It also integrates both theory and experiment and thus provides some concrete experience during the formation of abstract concepts. However it is not explicitly based on the Karplus Learning Cycle and thus we might expect that students at a concrete-operational level of development would be disadvantaged relative to formal-operational thinkers.

Results

The results of testing are shown in the Table. An A grade indicates that the student had completed four advanced modules, while a B grade required two advanced modules in addition to the ten modules required for a C pass.

Table: Cognitive level and performance in mechanics course (N=48)

Cognitive Level	Grade Obtained				Total
	A	B	C	Fail or withdrawn	
Formal	5	3	11	4	23
Transitional	3	2	8	6	19
Concrete	0	1	4	1	6

These results indicate that only 23, or 48%, of the class had reached the formal-operational stage of their intellectual development at the start of this course. However most of the class had developed some skills of formal, abstract reasoning and only 6, or 12%, were still at a purely concrete-operational stage. A chi-squared analysis of this data shows that there is no significant correlation between cognitive level and performance in the course. Although 83% of the formal thinkers and a similar proportion of the concrete thinkers were successful, only 68% of the transitional group passed. There is a higher proportion of As and Bs amongst the formal and transitional thinkers than amongst the concrete thinkers.

Discussion

Our results confirm the pattern established by cognitive testing in the USA (Cohen *et al.*, 1978; Liberman and Hudson, 1979). This is:

- less than half of the first year class had clearly reached the formal stage of their intellectual development,
- there is little correlation between cognitive level and performance in the physics course.

The reasons advanced for this lack of correlation are that other factors, including motivation, diligence, personal circumstances, mathematical and physical preparation, are also significant determinants of student performance. Other research has confirmed the importance of these factors (Hudson and McIntire, 1977) yet it does appear to us that cognitive level is still an important factor in physics education. By carefully analysing the experiences of the concrete-operational students in this course, through interviews with these students and their tutors, we established that all of them had great difficulty in understanding and using the material. Those who passed the course did so because of intense effort produced by strong motivation which was facilitated by some aspects of the course design (e.g. self-pacing). However few of them achieved anything other than a basic C pass. These students tended to work more diligently than those at higher levels of intellectual development because they were aware from the start that they would find the course difficult.

Analysis of the class records indicated that many of the students at the formal stage of development underestimated the difficulty of the course and tended to procrastinate. Students in the transitional group were particularly at risk because they found the early modules easy but were not able to cope as readily with the more advanced modules later in the course because of their less developed skills of formal reasoning.

Conclusions

The following conclusions have emerged from this study:

- We believe that we can explain the lack of strong correlation between cognitive level and performances in terms of a complex interaction between preparation, motivation, diligence, course design and intellectual development.
- Our results support the use of cognitive tests as diagnostic tools to identify students who will experience difficulty with the course. Once such students are identified by cognitive testing they may be given additional assistance or counselling directed towards their specific needs.
- The results also indicate that the transitional group of students may be at risk unless they are encouraged to work steadily through the course.

Finally, it is worth noting that previous findings (Jennings and Atkinson, 1982) support the use of the Karplus Learning Cycle in first year courses as an aid to concept development for students who have not reached the formal-operational stage of their intellectual development at the start of their university studies.

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Forthcoming Conference

The Third Applied Physics Conference of the Australian Institute of Physics will be held between 3-7th December 1984 inclusive, in Melbourne.

The host will be the Department of Applied Physics, Royal Melbourne Institute of Technology. Members will recall that this Department was the host for the second A.I.P. Conference.

The Conference theme will be "Physics and Australia's Resources". The first announcement and Call for Papers will appear in the next issue.

K.R. Cook
Honorary Secretary
3rd A.I.P. Conference.

Operation of National Research Granting Schemes

A Report to the Prime Minister by the Australian Science and Technology Council (ASTEC), Australian Government Publishing Service, Canberra 1983, 76 pp. Reviewed by S.P. Burley, School of Economics, La Trobe University, for the Science Policy Committee.

This report presents a compendium of the operations of the major national research granting schemes, and makes a number of very general suggestions as to how they might achieve a more effective promotion of research given their allocations of funds. These suggestions arise from a comparison of the workings of the different schemes, which comparison also indicates the desirability of each scheme to relate to the others. The report further suggests the provision of greater "administrative support" for some of the schemes by the Government, to enable "proper evaluations of progress achieved and the forward commitment of funds".

Nine specific recommendations are made, concerned with: annual reports of areas of strength and deficiency in the various areas, peer reviews, coordination, assessment of progress, stronger secretariats, more flexible uses of funds and forward commitment of funds. A perceptible overall suggestion appears advocating greater bureaucratisation of what has been largely a management by hard working committees of volunteer experts. This suggestion is not without foundation, but older hands will no doubt be alert for the first signs of any needless emergence of more administrators and controls.

For physicists however the most pertinent section of the report will probably be the last one, headed

"Provision of major equipment". This is a major and growing concern. The question is complicated by the normal division of equipment into "large", "major" and "small" with the middle group, \$0.2 to \$1.0 million proving the most difficult to handle. It seems to be too big for individual universities to handle comfortably and too small to warrant national involvement. The Committee draws attention to the possibilities of coordination but makes no formal recommendations concerning this whole problem in the present report. However it indicates that an "integrated solution" will be considered in its forthcoming report on research funding.

LETTER

Dear Sir,

I notice that for the AIP National Congress of Physics in Brisbane, all oral presentations will be invited papers of a review nature and contributed papers will only be presented in poster sessions. I am writing to suggest that such an organization of the timetable for a week long conference represents a lack of balance. Surely half of the time for oral presentation could be devoted to local research contributions. We don't only want to hear general talks on 'appropriate technology' and 'nuclear warefare issues'.

I realize that in the past Australian research in physics has been weak, and that it has been usual in Physics Congresses to go along and either meekly listen to invited talks from overseas experts who have been flown in, or else listen to review lectures, again largely of overseas developments, as perceived by respected local professors, who frequently spend most of their time in administration.

I believe that there is now local research work done by individual scientists in Australia which is world class. There should be an opportunity for such work to be presented orally. There can be considerable stimulus in an oral presentation to publicize work, and gain from the general reactions and questioning from an audience. Presentation time for each paper can be quite short. At some conferences of the American Physical Society it is only 7 minutes.

I know that it is said that poster presentations have just as much status as oral presentations. Yet the high status professors don't seem to rush to contribute to poster sessions, whereas they often feel very honoured to be asked to given an oral presentation.

John J Lowke
Division of Applied Physics,
CSIRO