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An approach to the teaching of the wave model of light using microwaves

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In the schools of Victoria, Australia, students study an integrated science course in the first four years of secondary school (Grades 7 to 10), and some students elect to study one or more of physics, chemistry and biology as separate subjects in Grades 11 and 12. The average age of Grade 11 students in Victoria at 1st August 1969 was 15 years 9 months, with an effective age range of 15 years to 18 years. For Grade 12 students the average age was 16 years 9 months, and the effective age range 16 years to 19 years.

The physics course in Grades 11 and 12 in Victorian secondary schools is based on the Physical Science Study Committee (PSSC) physics course (PSSC 1965), which has been divided into two parts, one for each of the two Grade levels. The Grade 11 course has been designed to be a terminal course in itself, and is based on Part I of the PSSC text, Part II of the text up to the use of the wave model to predict Snell's Law, the early chapters of Part III of the text, and the introductory chapters on electricity and magnetism from Part IV of the text. At the end of Grade 12 all students present for Higher School Certificate examination, conducted by the Victorian Universities and Schools Examinations Board, which is based on the entire PSSC text.†

This article reports the results of an alternative approach to the teaching of the wave model of light to that used in the PSSC text. In this approach, three Grade 11 classes in a large suburban high school in Melbourne were taught the entire PSSC section on light, including diffraction and interference, using microwave equipment rather than the PSSC course approach. The performance of these students was compared with students in Grade 12 in the same school who had studied interference and diffraction by the PSSC approach in their Grade 12 year. One difficulty in this comparison was that only about 60% of Grade 11 physics students go on to study Grade 12 physics, and in general, those who continue are the most able students in physics.

†The Grade 11 and Grade 12 courses are described in detail in *Handbook of Directions and Prescriptions* of the Victorian Universities and Schools Examinations Board (VUSEB 1969).

Objectives

Six objectives were defined for the teaching materials developed for this experiment. They are listed below. At the conclusion of this unit of study the student should be able:

a to compute the positions in either angular or cartesian terms of maxima and minima in (i) double-slit interference patterns and in (ii) single-slit diffraction patterns;

b to differentiate between examples of single- and double-slit interference patterns;

c to recognise pairs of single two-dimensional pulses that would destructively interfere if they were to meet while travelling in opposite directions in the same medium;

d to identify the conditions under which a standing wave pattern may be formed and locate the positions and state the number of nodal points formed in such patterns;

e to comprehend the differences between the terms 'wave length', 'frequency', 'period' and 'velocity' of travelling waves, and to apply relationships between these quantities to calculate one of these quantities from values of others;

f to define the term 'continuous waves' in their own words.

Teaching materials

(i) The teaching materials used in this experiment consisted of a set of supplementary notes for student use. The style of presentation in the notes was as close as possible to the style of the PSSC text, but the notes were presented in a work-sheet format. Where appropriate, students were referred to illustrations, diagrams and problems in the PSSC text.

(ii) Videotapes were prepared at Monash Teachers' College and were shown to students at appropriate times during the course.

(iii) A UNILAB 3 cm microwave generator and detector were used for demonstration purposes.

Outline of the course materials

The general theme of presentation was one of guided discovery. The following was the order in which the students proceeded.

(1) Students observed the properties of reflection, refraction, focusing and formation of shadows with microwaves and compared these observations with observations with light.

(2) Students were asked to predict what would be observed when microwaves were passed through a double slit. Most students based their prediction on the particle model and were surprised when a multifringe pattern was observed.

(3) Students commenced the search for a suitable model to explain their observations with microwaves passing through a double slit. Students were guided to a wave model after observing waves, standing waves, pulses and interference effects on strings and in ripple tanks.

(4) Students calculated the wave length of microwaves using the wave model and measurements made from the double slit interference pattern. At this stage considerable practice was given in problems involving the use of scale diagrams. Students were then asked to predict the distances between successive nodal points in a microwave standing wave pattern.

(5) Students experimentally verified their predictions in relation to nodal points in a standing wave pattern produced with microwaves.

(6) Students observed double-slit and single-slit interference patterns with light. The theoretical relationships between wavelength, slit size and angles of maxima and minima intensity were derived. In these derivations considerable use was made of the techniques of scale drawing mentioned in (4).

Throughout this sequence the appropriate experiments from the PSSC laboratory guide were performed.

Evaluation of the materials

Three classes of Grade 11 physics students from the high school (69 students) were taught the relevant section of interference and diffraction by the alternative approach using microwaves. The performance of this group was compared with the Grade 12 students in the same school (53 students) who had studied the same content area using the PSSC course materials. It has already been noted that only the most able students continue to Grade 12 physics, so that the Grade 12 students should be superior in physics ability to the Grade 11 students. Evidence of results obtained on external examinations set by the Victorian Universities and Schools Examinations Board in physics indicate that the percentage of pass of these Grade 12 students at the 1969 Matriculation physics examination was not significantly different from the overall percentage pass rate for all students.

A criterion test which consisted of 14 multiple choice or short-answer items testing each of the six objectives laid down for the materials was prepared. This criterion test was used to compare the performance of the Grade 11 students taught by the microwave approach and the Grade 12 students taught by the PSSC approach. A second criterion test consisted of questions from examination papers in Grade 12 physics set by the Victorian Universities and Schools Examinations Board in the years 1966–8, covering some of the objectives *a–f*. For these questions a detailed analysis of the performance of a sample of all students presenting for the examination was available†. The performance of the Grade 11 students was compared to the State-wide sample of Grade 12 students on these items from Higher School Certificate physics examinations.

It was argued that, considering the differences in ability which were expected to exist between students in the Grade 11 and Grade 12 groups, it would be expected that the more able students attempting Grade 12 studies would perform better on the criterion measures than Grade 11 students. If no difference was observed between the performance of the Grade 11 and Grade 12 students on the criterion measures, the microwave approach would be regarded as successful, and as being a suitable alternative to the PSSC approach to the teaching of the wave model for light.

For the first criterion test of 14 items based on all six objectives of the course the mean score obtained by students in the Grade 12 group was significantly higher than for the Grade 11 group. The results on

†These analyses prepared by the second author are listed in the references (Mackay 1967, 1968, 1969).

the first criterion test are summarised in table 1.

A detailed analysis was then undertaken to determine if differences in the two groups were specific to a number of objectives. There was no significant difference between the Grade 11 and Grade 12 groups on items testing objectives *a* (i), *a* (ii), *d* and *f*. The Grade 12 group performed significantly better on items testing objectives *b*, *c* and *e*. These results are summarised in table 2.

The 9 items from previous examinations conducted by the Victorian Universities and Schools Examinations Board used as the second criterion test tested objectives *a*(i), *a*(ii) and *d*. No statistically significant difference was obtained between mean scores on this

Table 1 Mean scores of Grade 11 and Grade 12 groups on the 14 item criterion test

Group	N	Mean Score
Grade 11	69	6·82
Grade 12	53	7·65

Table 2 Mean scores of groups of Grade 11 and Grade 12 students on items on each of the 6 objectives

Objective	Number of items	Mean score: Grade 11 students (N=69)	Mean score: Grade 12 students (N=53)	Significance of difference
a(i)	3	1·13	1·22	not significant
a(ii)	2	0·47	0·69	not significant
b	2	1·20	1·55	difference significant
c	1	0·52	0·77	difference significant
d	2	0·90	0·71	not significant
e	2	1·92	1·72	difference significant
f	1	0·64	0·68	not significant

Table 3 Mean scores of Grade 11 students taught by the experimental course and samples of Grade 12 students taught using the PSSC course on the second criterion test

Group	N	Mean Score
Grade 11	69	5·65
Grade 12	230	5·91

second criterion test of the Grade 11 group of students taught the microwave course and the samples of Grade 12 students taught by the PSSC course. The results are summarised in table 3. These results were consistent with the results obtained on objectives *a*(i), *a*(ii) and *d* on the first criterion test.

Discussion of results

The Grade 12 students returned a slightly better performance on both criterion tests. This would be due partly to the selection of students that occurs at the end of Grade 11 and the greater maturity of the Grade 12 students.

When the performance of the two groups on each of the 6 objectives defined in this study were analysed it was found that no statistically significant difference existed between the performance of the Grade 11 group taught with the alternative materials and the Grade 12 group who used the PSSC course materials on objectives *a*, *d* or *f*. This result was obtained for both criterion tests. On these 4 objectives, it was therefore concluded that the alternative approach was no less successful than the PSSC approach.

The Grade 12 students performed significantly better than the Grade 11 students on items testing objectives *b*, *c* and *e*. Both items testing objective *b* involved a recognition of intensity versus distance graphs for interference patterns. The better performance of the Grade 12 students suggests that Grade 11 students had not fully understood these graphs and their relationship to observed interference patterns. The alternative course would require strengthening in this area.

The better performance of Grade 12 students than the group of Grade 11 students on the items testing objective *c* was a complete reversal of the predicted result. The alternative course emphasised this aspect in the treatment of standing waves, and the students had previously completed the relevant part of the PSSC course. No reason can be advanced for this result.

It was felt that both items testing objective *e* in the criterion test were too easy, as indicated by their low percentage difficulty, to adequately discriminate between students in the Grade 11 and Grade 12 groups. Although the alternative course differed from the PSSC course in this section, appropriate problems from the PSSC text were used as practice examples for both groups of students. It was concluded that both the microwave approach and the PSSC approach were satisfactorily achieving this objective.

In summary, the alternative course materials based on the use of microwaves to establish the consistency of the wave model of light with observed interference and diffraction phenomena for light proved to be successful, although a number of areas were identified in which the materials could be advantageously improved. The reaction of students and teachers who used the experimental materials towards these materials was one of enthusiasm.

References

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Physics apparatus

Pocket-size Microscope

Colebrand Ltd
15 Hampden Gurney Street
London W1M 5AL

The accurate measurement of crack widths down to as little as 0·01 mm is claimed for the 'Lomara' range of pocket size microscopes. The model with battery operated light attachment is small enough to fit into a jacket pocket.

The versatility of these robust but precise instruments — available in a range of three basic models commencing with model no 705 which has magnification of from 40× to 120× (without scale) to the model no 250C with 100× magnification and a scale of 1/100 mm — will ensure their acceptance for many measuring purposes such as assessment of cracks in concrete and other structures, examination under difficult conditions, or restricted access, in workshops and laboratories in colleges and other educational establishments where its relative cheapness will be an advantage.

All except the model no 705 can stand unsupported on level surfaces. The microscope with light holder is powered by a 3 volt torch battery. All except the model no 705 are complete with case.

Price: from £9·50 to £30·50.

Compukit 2

Limrose Electronics (P)
Lymm
Cheshire

Limrose Electronics have added to their 'Compukit' range a new integrated circuit patchboard system which is especially suitable for schools and colleges for teaching advanced logic and for rapidly simulating complex industrial digital and analogue systems.

The patchboard system, Compukit 2, accommodates twelve 14 or 16 pin dual-in-line integrated circuits, which are connected together using a reliable multicoloured solderless patch lead system and gold-plated terminal pins. Each output has two pins, so that multiple connections to any particular point can be easily made. There are ten transistor driven indicator lamps to monitor the outputs, and a six switch input register provides independent logic inputs to the system. An additional feature is a two-speed clock, the low speed of which can be used for demonstration. The patchboard is housed in a handsome cabinet which is fully portable, and has no trailing wires when used with the internal battery power supply. It can be used with one, or more, external power supplies as required permitting use of analogue and digital modules simultaneously. Two or more units may be connected together for simulating larger systems.

An educational pack consisting of the patchboard, 48 patch leads, a selection of ten integrated circuits and a logic instruction book, costs £62. The price of the patchboard complete with logic indicators, clock unit, input switches and 48 patch leads is £48.