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Why Physics Seems to Be Beyond Some Students' Grasp

Susan Gatt
Faculty of Education, University of Malta, Msida.

It is quite common for many students to complain about having to study physics. Some clearly state that it is not a subject of their interest, and even more find understanding physics to be beyond their capability.

The rate of failure in the subject is quite high. As can be seen from the results in the SEC physics 1996 May session, about half the students (47%) did not get the required pass mark to proceed with their studies. In addition, most of the grades were in the 4-5 region, showing that performance was not of a high standard (Table 1).

Grade	No. of Candidates passing	% candidates passing
1	55	2
2	82	3
3	136	5
4	652	25
5	483	28
6	454	27
7	240	9
U	543	21

Table 1. Grades obtained in SEC Physics exam in May 1996 Session (MATSEC, 1996) No. of Candidates: **2645**; No. of candidates opting for paper 2A: **1097**; No. of candidates opting for paper 2B: **1548**.

What is it that seems to hinder students' performance in physics? Science educators, teachers and politicians have always shown concern for the problem with physics, and a number of possible reasons have been put forward. The major arguments involve the difficulty in understanding concepts in the subject, teachers' professionalism and pupils' ability.

- **the nature of knowledge of physics:** The knowledge of physics tends to be objective, involving considering mechanisms and physical phenomena around us. However useful these things may be to the commodity of our everyday life, they do not seem to be of such great interest to young teenagers, especially girls who tend to be more interested in the social rather than the physical aspect of our society (Head, 1980, 1985). On the other hand, boys seem to be enthusiastic initially but interest wanes at the end of secondary education.

- **the level of concepts involved:** Many of the concepts involved in physics are abstract in nature and not easy to understand. Relationships often involve more than two variables and some ideas cannot be visualised. Concepts like density and acceleration involve a combination of three variables, while magnetic fields and field lines are difficult for students to conceive.

- **teachers' professionalism:** One may easily blame teachers for poor teaching ability as one major cause of the problem. While this argument may hold in some cases, it may be possible that even with the best teachers the problem lies with the students. There must, therefore, be other factors involved.

- **students' ability:** Likewise, the understanding and absorption of the concepts covered is often attributed to the students' mental ability. Teachers very often witness students trying to make sense of physics with no success. If so, what level and what type of mental ability is required, and what can we do to help students?

The main argument of this article concerns the demand of concepts found in physics and whether Maltese students in secondary schools have the required mental ability to grasp such concepts.

Cognitive development in adolescents

Most of the major work in cognitive development was carried out by the famous psychologist Jean Piaget, who developed the levels of cognitive development through which students evolve during their childhood (Inhelder and Piaget; 1958). The main levels of development of interest at secondary level are the ***concrete operational*** and ***formal operational*** stage.

Concrete Operational Stage

At this stage, thought is very much tied up with concrete situations. Unless the pupils have the apparatus in front of them, or a diagrammatic representation of the situation, they will not be able to formulate thoughts about it. In addition, at this level, children cannot consider more than two variables at one time. So, as Inhelder and Piaget (1958) first reported and Shayer and Adey (1981) later described, students considering the reason why some objects float and others sink, may reason in terms of whether an object is light or heavy, rather than use the concept of density.

Formal Operational stage: At this level thought is considered to be hypotheticodeductive. This means that thought does not need a concrete situation to occur, but rather the other way round. A developed formal operator, or abstract thinker, will be capable of, not only to think out an idea, but also to consider all the variables (more than two) and devise a fair test to test out his/her hypothesis. In the same example cited by Shayer and Adey (1981), students will now be able to consider the combination of mass with volume in density and to be able to devise an experiment, controlling the variables, to test it out.

It is important to point out that the model is developmental in that students have to go through the concrete operational stage before reaching formal operational thought. In addition, it is a slow process, and development occurs gradually.

The Physics Syllabus

One need not have a background in psychology to realise the curriculum demand of the subject. At this stage one may pose the question of how cognitively demanding can physics actually be? What is the minimum cognitive level of development required to be able to understand the basic concepts? The various sections of the physics SEC syllabus are considered and their average level of demand noted. Table 2 lists the minimum cognitive level necessary to just follow the course as compared to that

Topic	Minimum level of cognitive development required to follow	Maximum level of cognitive development required to fully understand
Structure of Matter & Kinetic Theory	**3A** Abstract model used to explain behaviour of gases gas expands due to greater vibration.	**3B** Understanding of gas laws - manipulation of pressure, volume & temperature.
Energy	**2B** Work as using energy Energy has many sources.	**3B** Heat can only be partly converted into useful energy. Different energy needed to stop cars of different velocity.
Waves	**3A** Equation $v=f\lambda$ known as an algorithm light as part of electromagnetic spectrum.	**3B** Understanding difference between longitudinal & transverse waves. Relating velocity to wavelength & frequency.
Charge & Current Electricity	**2A** Bulbs light when connected to batteries Bright bulb has more energy than dim bulb.	**3B** Meaning of potential as work done in transfer of energy between two points.
Pressure	**2A** Force = Pressure. Same force acts more over a small area than a large one.	**3A** Can understand that pressure in liquids depends on height, not on cross-sectional area.
Linear Motion	**2A** Intuitive notion of speed. Speed & position of departure not differentiated.	**3A** Acceleration qualitatively understood as rate of change of velocity.
Magnetism & Electro-magnetism	**2B** Can understand that like poles repel, unlike poles attract.	**3B** Understand nature of fields ; effect of motion & current in magnetic field, motor, generator.
Optics	**2B** Light travels in straight lines Angle of incidence = Angle of reflection.	**3A** Can use lens laws (ray diagrams) but as algorithms.
Electronics	**3A** Gates : known as algorithms.	**3B** Understand the use of gates in practice : alarms etc.

Table 2. Minimum and Maximum levels of cognitive development required to follow Physics SEC course. (adapted from Shayer & Adey,1981) (2A - Early Concrete operational; 3A - Early formal operational; 2B - Late concrete operational; 3B - Late formal operational)

necessary for fully understanding physical ideas and their implications. If one would like students to understand physics, formal operational thought is required in most cases. as is indicated in Table 2. Physics includes many concepts which are abstract in nature. Often mental models are used to explain phenomena. A topic like kinetic theory involves the use of a mental model to represent particulate structure and is all abstract in nature. No wonder it is one of those topics many students fail to grasp. Other instances of abstract notions like magnetic fields, electric charge, cutting of flux etc., form the basis of physics throughout, and unless students have the mental ability to manipulate such ideas, their level of understanding will be limited to simple one way relationships and mechanical manipulations of formulas. Students may still manage to get through the SEC exam but a very limited insight would have been achieved.

This leads to the question of whether Maltese secondary school students have developed a basic level of abstract thinking to understand physics and if not, is it one of the reasons for their difficulty with the subject? Several pilot studies have been carried out (Andrews, 1979; Attard, 1989; Busuttil, 1981), but although similar trends have been obtained in the UK, all three studies seem to indicate that Maltese students lag behind in development. However, the samples considered each time were small and non-representative, and have to be interpreted with caution. The results of the research considered here include a greater student population and thus may give a clearer picture of the situation in general.

The sample used for this study consisted of 814 Form IV students from Junior Lyceum schools, of whom 458 were girls and 356 were boys. The test used was the Science Reasoning Task, the pendulum having an internal consistency 0.83 (Shayer and Adey; 1981). The instrument was devised and tested by Shayer and Adey (1979) and used in a study involving about twenty five thousand students in the UK The pendulum task was chosen as it differentiates between late concrete and formal operators, and was therefore suitable for our sample. The test consisted of twelve items, was held in class, and involved a class demonstration using the apparatus. Each question was explained and the students wrote their answers on the questionnaires. Care was taken to explain the questions in Maltese to avoid language difficulties. Table 3 below outlines the results obtained.

Level of Development			% Students at Form IV
2B	:	Concrete	31.3
2B*	:	Mature Concrete	47.3
3A	:	Early Formal	19.8
3B	:	Mature Formal	1.6

Table 3. Level of Cognitive Development in Form Four Junior Lyceum Students.

As one can easily note from Table 3, only about 20% of Form IV students achieved some form of abstract thinking. The rest of the students were still at an earlier stage of development. Taking Junior Lyceum students to represent the top 55% of the student population for that year, the results obtained show that Maltese students are at a similar level of development to that of students in the UK (Shayer and Adey, 1981). This result differs from other small studies mentioned above, and is believed to be more indicative. However, one must not forget at this stage that only Junior Lyceum students were tested, and that a significant percentage of students attend private, church or area secondary schools. The sample considered is, therefore, probably not representative of the whole top 55% of the student population in that year.

Another implication of the findings, relevant to the argument in question, is that less than a quarter of students in Form IV have developed abstract thinking and that the conceptual demand of many topics in physics is beyond the mental ability of our students. A more interesting result transpires when level of development is considered across gender. As Table 4 below shows, girls in Government Junior Lyceum schools are at a higher level of cognitive development than boys of the same age.

Level of Development	Boys (%)	Girls(%)
Concrete	36.2	27.5
Late Concrete	47.5	47.2
Early Formal	14.9	23.6
Formal	1.4	1.7
Total	**100**	**100**

Table 4. Level of Cognitive Development in Form IV Students across Gender. χ^2- 12.6; $p < 0.005$.

One must note here that the population of boys in government schools is less than that of girls, and since a significant proportion of the total Form IV students go to church or private schools, one cannot extrapolate these results to the whole population. What can be said is that girls in Junior Lyceum schools are at a more advanced level of development than boys in Junior Lyceum. T-test analysis carried out on the actual scores showed that the means for boys and girls were 6.11 and 6.31 respectively, and found to be statistically significant ($p < 0.001$). If the subject matter seems to be too demanding for the students, does it lead to the conclusion that the curriculum needs to be changed to fit the students' ability? The question of matching has been debated in the UK in the '80's and the general consensus that has emerged is to stick to what we have.

Another possibility, to tackle this mismatch, is maybe to help students develop abstract thinking so that more students would be able to grasp the concepts. Researchers from King's College, London claim to have managed to achieve this throughout a programme known as Cognitive Acceleration through Science Education (CASE) (Adey, 1992). Would the implementation of this programme solve all our problems?

It would be wiser to look at the ways and methods included in such projects and to learn about the approaches and methodology employed. However, two main points need to be considered, the first involves what level of subject matter needs to be taught, and the second is how this subject matter is going to be taught.

Following Vygotsky's (1978) idea of zone of proximal development, subject demand should be just beyond the students' present level of development. According to Piagetian theory, a student at a concrete level of development will never be able to grasp concepts requiring abstract thinking, however hard she/he tries. This line of thought would negate all possibility for teaching physics successfully at secondary level. Vygotsky's argument, however, runs differently. According to Vygotsky, there is a difference between what the student is able to do on his/her own, and what she/he can do with the help of a teacher, or a mediator. The difference between these two levels is known as the **zone of proximal development**, and teaching should be pitched at this level. The implication is that if at the age of 13-15 students fall mainly at the late concrete operational stage, then teaching should be at the early formal level. So, physics can, and should, be taught to students at secondary level.

Learning and development are not two separate things and one cannot wait for development to expect learning. On the contrary, learning and development go hand in hand. As students learn, development occurs, promoting further learning. Teaching science is not solely the vehicle to promote scientific knowledge, but is also a powerful tool to help adolescents undergo cognitive development.

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