The Cognitive Developmental Levels of a Sample of First Year University Science Students

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Abstract

The purpose of this study was to gauge the cognitive developmental levels of first year university science students. The sample consisted of 386 third-level students, with an average age of 18.8 years. The sample was comprised of two first year groups of students, from nine undergraduate science courses. The task used to measure the cognitive developmental levels was one of the Science Reasoning Tasks, developed by the CSMS (Concepts in Secondary Mathematics and Science) team. The profile obtained showed that almost 70 per cent of students were at levels capable of formal operational thought. However, only a very small minority showed capability of late formal operational thought, necessary for meaningful engagement and understanding of many scientific and mathematical concepts. Thirty-two per cent of the university cohort was at concrete levels of cognitive development. A statistically significant gender difference was evident in this study with female students lagging behind male students in this sample, in terms of their cognitive developmental levels. The significance of these results is evident when the students' current cognitive levels are compared with the minimum cognitive level that a student should be at, in order to understand a large amount of scientific and mathematical concepts in second and third level education. More detailed analysis of these results and the implications for third level science education are presented.

1 Introduction

The link between cognitive development and maturation was suggested by Piaget in terms of his stage theory. He proposed that individuals pass through distinct stages of development namely, the sensori-motor, pre-operational and operational stages. Piaget described three major stages that all children go through in the development of their cognitive skills. The behavior and thinking abilities displayed by all children within each stage is similar, both between different contexts and different children. The general age/ stage picture, presented by Piaget is shown in Figure 1.

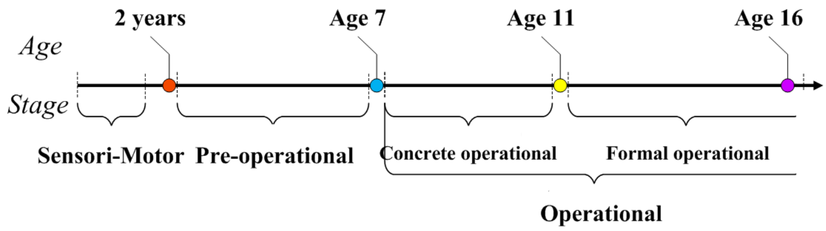

Figure 1: **Time-line of Piagetian stages of cognitive development**

Tools which assessed stages of cognitive development with large class sizes were developed by the Concepts in Secondary Mathematics and Science (CSMS) team and were published as Science Reasoning Tasks [1]. Their function was to assess the ability of children or adults to use concrete and formal reasoning strategies, as described by the Piagetian stage theory. Each of the stages of cognitive development were divided into late and early stages and Adey and Shayer [2] use the notation shown in Table 1 to indicate stages and sub-stages of the cognitive development scale.

Table 1: **Stages of development, corresponding notation (compiled from [2] and [3]) and approximate ages**

Piagetian Level	**Notation**	**Age (years)**
Pre-operational	1	
Early concrete operational	2A	5/6
Mid concrete operational	2A/2B	7/9
Late concrete operational	2B	10/11
Transitional	2B/3A	
Early formal operational	3A	11/13
Formal generalisation	3B 14/15	

In the original research the CSMS team surveyed approximately 14,000 students, between the ages of 10 and 16 years, from nearly 50 (middle, comprehensive and selective) schools in Britain and Wales. There were between 1000 and 2000 students for each year of age. The results, as displayed in Figure 2, show the proportion of children at each age, who are at or above each stage of development.

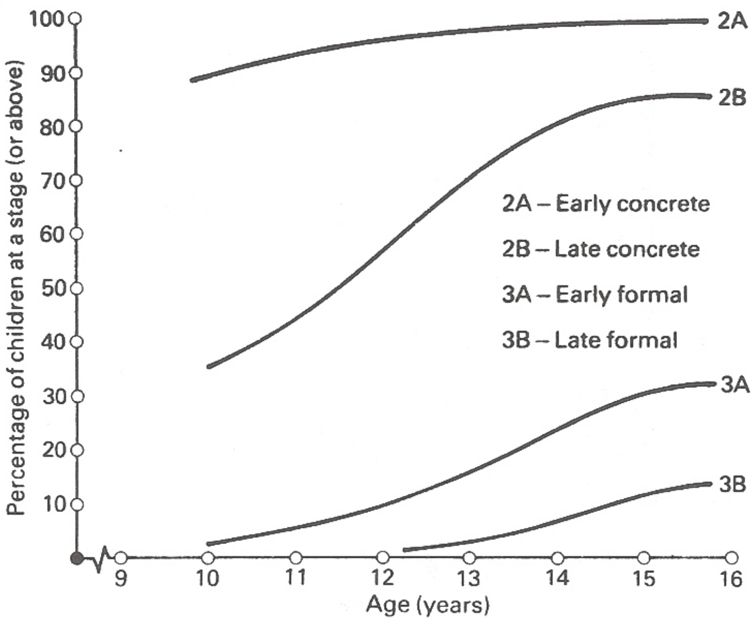

Figure 2: **Results from the CSMS survey; Proportion of children at different Piagetian stages in a representative British child population (taken from [2])**

Adey and Shayer's data for the representative population shows that by the age of 14 years just over 20 percent of students are at or above the early formal operational stage of thinking [2]. Not only does this contradict the Genevan age/stage model, it also highlights more serious implications in terms of meaningful engagement with science and mathematics. If only 20 percent of the sample population are at the early formal operational (3A) mode of thinking it implies that up to 80 percent are not at this level and hence will have serious difficulties comprehending the sort of abstract models, such as atomic theory, that comprise much of the science curricula.

In summary, the results from the CSMS survey showed that;

- The spread of ability was wider than expected. A school group, with an average age of 12 years, contained students who reasoned as average 8 year olds and others whose thinking is similar to the top third of 16 year olds;
- Only about 30 percent of students at the ages of 14/15 years demonstrated formal operational thinking;
- A more recent study by Shayer *et al.* [4] showed that there was a large drop in the competence of 11 to 12 year-olds in their performance on cognitive tasks between 1975/76 and 2000/01.

More recently a profile of the cognitive developmental levels of Irish students from the ages of 12 to 14 years was obtained [5]. In summary this profile indicated that the sample of Irish students tested were at cognitive developmental levels that were behind that expected for their age. In addition, it showed that the majority of students were at levels which were insufficient for meaningful engagement and understanding of many Junior Certificate science and mathematics concepts. This conclusion was made based on the Curriculum Analysis Taxonomy, developed by Adey and Shayer [2]. This was a tool developed to assess the cognitive demand levels of scientific and mathematical concepts in the second level curriculum. The taxonomy consisted of two sections, the first of which detailed the psychological characteristics of children's thinking, such as use of models, types of categorization and investigation style. The second characterized children's responses to particular types of problems, such as conservation, control and exclusion of variables and mathematical operations. For both sections Adey and Shayer characterized the responses from early concrete (2A) to late formal (3B). The taxonomy was then used to match the objectives of the curriculum with the necessary cognitive level for understanding. As part of the development of the Curriculum Analysis Taxonomy, its validity and reliability were tested and reported by Adey and Shayer [2].

The purpose of this study was to gauge the cognitive developmental profile of first year university science students in order to determine the proportions at concrete and formal operations in third level education. This was done to determine if by the age of approximately 19 years that they had all reached their optimum cognitive developmental level and hence have the ability to understand science concepts as proposed by the Piagetian model.

2 Cognitive Development Assessment Instrument

2.1 Instrument and Administration

The tool selected to assess the cognitive levels of the students was *Equilibrium in the Balance*, the fourth in the series of the SRTs. This task assesses cognitive development levels between the ranges of mature concrete (2B) and formal generalisation (3B). The task contains thirteen items and investigates the student's ability to recognise and use inverse proportions in a balance beam. Towards the end of the task, proportions and the work principle are introduced, only accurately conceptualised by a late formal thinker.

The task requires demonstration, and students respond to questions via a worksheet. Although the worksheets had the basic questions printed on them, each problem was talked through in a way that was appropriate for the students. The idea of this is to aid students as students can only answer a question to the best of their ability if they fully understand what is been asked. They are encouraged to ask if they do not understand what is required of them and the question is re-posed to the entire student group. Another important feature of the SRTs is the feedback that is received by the subject in manipulating the apparatus in response to students' ideas about different aspects of the problem. Thus the demonstration forms a central role to the task.

Students' responses are given scores of either '1' if correct or adequate and '0' if incorrect. The final score each student obtained was matched with a corresponding numerical scale and Piagetian level, representative of the student's stage of cognitive development.

2.2 Development and Verification of the instrument

This SRT, as well as the others in the series, was evaluated in a rigorous manner by the CSMS team in terms of their reliability and validity [1]. The reliability of the tests was investigated in two ways. The internal consistency was measured by the Kuder-Richardson coefficient, r_{tt} and the value obtained for the *Equilibrium in the Balance* task was 0.84. A r_{tt} value of 1 would imply perfect internal consistency, suggesting that all the tasks were telling the exact same story. The second method, test-retest reliability was used to measure the extent to which a task will tell the same story on two successive occasions. The same students were given the same task twice within a three to six week period and the reported value for the task was 0.78, as shown in Table 2. The standard error of measurement for a single task is reported to be about 0.55 levels, on the seven point interval scale [6]. This means there is about 95 per cent probability that a subject's true score lies within a range of +/- 1.1 levels of the measured score. For instance, if a student attains a 3A level there is a one in twenty chance that the student's true score does not lie between the 2B/3A-3B range.

Table 2: **Statistical Reliability and Validity of Science Reasoning Tasks (SRTs) [2]**

Number and Name	**Internal consistency**	**Test-Retest correlation (N)**	**Task-interview correlation (N)**
IV Equilibrium in the Balance	0.84	0.78 (31)	0.55 (18)

Detailed studies of content, construct, concurrent and predictive validities have been carried out and reported by Shayer [7, 8]. The content validity test basically measured whether the SRTs measured the same thing as the original Inhelder and Piaget tasks. A sample of pupils who took each task were interviewed individually in line with Piaget's own technique. The results, shown in Table 2, show the correlation between levels assigned by the tasks and by the interviews. The correlations between the group tests and interview results are reported as 0.55 for the *Equilibrium in the Balance* task. Furthermore, a comparison of SRT and individual interview mean levels show no systematic difference [1]. In addition, the group tasks were more reliable than the interviews as a measure of the stage of cognitive development. Shayer and Adey [2] believe that the extra source of variance in the interview technique arises from the personal interaction between the interviewer and interviewee.

In this study, the Cronbach's Alpha co-efficient for the task was 0.7, deeming it to be internally consistent.

2.3 Sample

The sample of 386 students were from nine first year science courses (mostly chemistry based), from two consecutive year groups. The average age of the cohort was 18 years and 10 months. The sample was comprised of approximately 45 percent male and 55 percent female students. The task was administered on both occasions by the researcher, at the beginning of the academic year.

3 Results and discussion

The Piagetian levels of the cohort (N=386) are displayed in Figure 3. It can be seen that 67 percent of the students are at the formal operational levels, with the majority (36 percent) at the early formal (3A) level. According to Piagetian theory, by the age of 14/15 years children should be at the late formal (3B) operational level. However, in this sample only 7 percent were at the 3B level. 32 percent of this university sample were at the concrete levels of cognitive development.

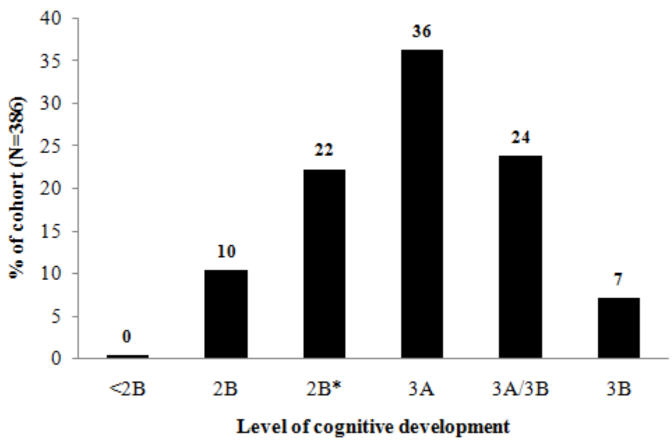

Figure 3: **Piagetian levels of 1st year university science students (Average age 18.8 years)**

In terms of gender, there was a statistical significant difference between the male and female groups, with the males at the higher levels of cognitive development. Figure 4 shows the profile of Piagetian levels for the gender groups. 56 percent of the female group, compared with 80 percent of the male group, displayed formal operational thought. One of the greatest differences between the groups was at the late formal operational level, with 14 percent of males at this level compared with just 1 percent of females.

Some of the 1st year cohort (N=106) studied physics for the Leaving Certificate course, the final two years in second level education. Assuming that these students studied the concept of equilibrium in detail as required according to the Leaving Certificate physics curriculum, it was decided to remove these students from the sample. Figure 5 shows the the profile of the 1st year students, when this group was removed. This profile is comparable to that of the entire

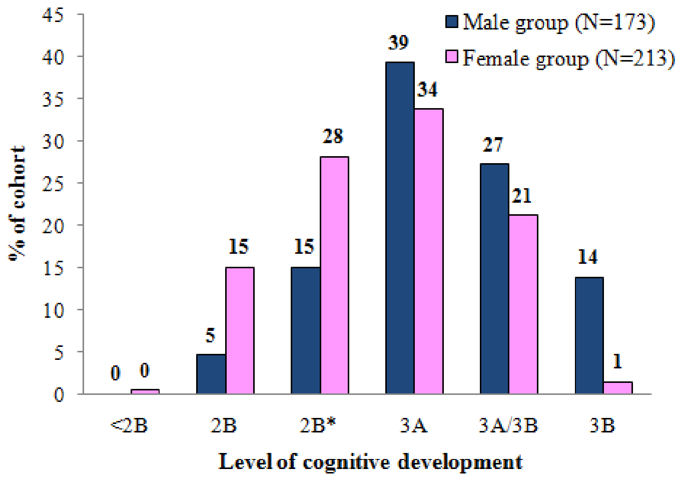

Figure 4: **Piagetian levels of 1st year university science students, based on gender**

cohort. 60 percent of this sample display formal operational thought, with the majority (33 percent) of these at the early formal (3A) level.

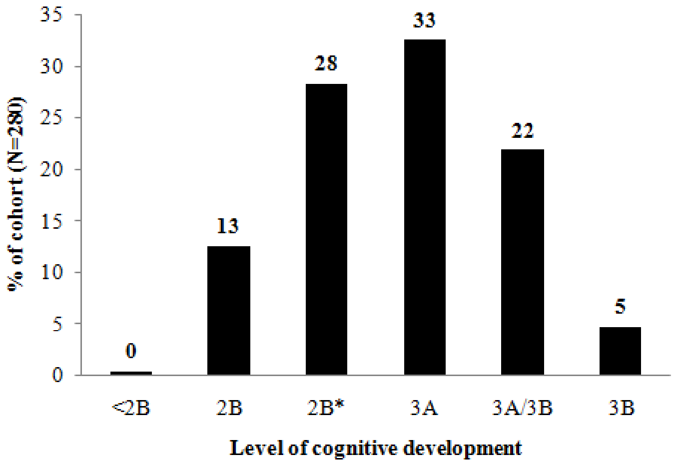

Figure 5: **Piagetian levels of 1st year university science students (without the Leaving Certificate physics cohort)**

An analysis of the gender differences show that yet again there was a significant difference between the genders, with the male group displaying more competence in formal operational thought than the female group. The profile, according to gender, can be seen in Figure 6. It can be seen that there was a much greater proportion of the female group at the concrete operational (50 percent) levels, compared with the males (28 percent).

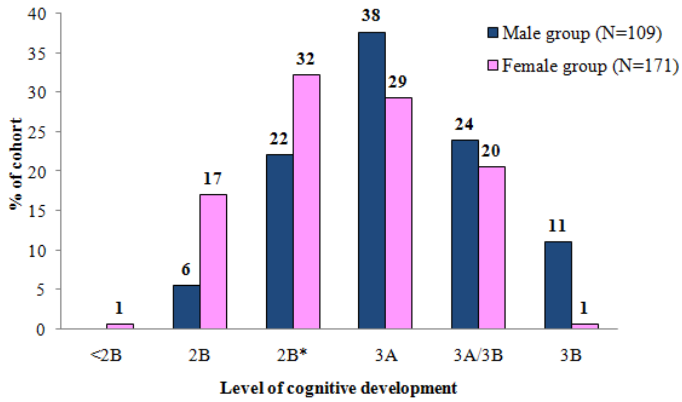

Figure 6: **Piagetian levels of 1st year university science students, based on gender (without the Leaving Certificate physics cohort)**

4 Conclusion and Implications

This study yielded a profile of cognitive levels of students that choose to study science at third level. A very small proportion of the sample of students displayed late formal operational thought, necessary for competence in operations such as proportionality, equilibrium and formal modeling. This finding is a major cause for concern on a number of levels. The profile implies that a majority of these students have proceeded through second level education successfully without fully developing their cognitive abilities. The majority of these students had a science subject to Leaving Certificate level, which when roughly compared with the Curriculum Analysis Taxonomy implies that formal operational thought is necessary. However, this profile implies that perhaps the students did not interact with the content and yet despite this they successfully completed the course. There is further concern for the students in third level education where the content requires formal operational thought for true understanding. On a more general level the profile suggests that the current systems have not succeeded in aiding students to reach their potential in terms of cognitive ability. This study highlights the need for third level instructors to gain better understanding of the cognitive developmental profile of their students. Knowledge gained by an instructor about their students' cognitive levels helps to inform them better about their students' capabilities and helps them to design and provide more effective instruction.

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