Gender Differences in Students' Understanding of Light and Sight

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ABSTRACT

The paper reports on the results of a study on how Secondary 3 and 4 (Grade 9 and 10) students from six schools interpret everyday phenomena involving light and sight. The test instrument was administered to 237 students. A Students' Seeing Framework (Jones et al., 1995) which was constructed from three primitive notions (light, eye and sight) served as the basis to analyse and evaluate students' responses. Statistical analyses were carried out to determine the gender differences with respect to the students' responses.

Introduction

Many researchers are puzzled by the phenomenon that students perform well in written examinations but are unable to explain everyday events. For instance, Gunstone and White (1981) showed that many students could do well in examinations but used naïve ideas to account for certain daily events. They went through 468 first year Physics students' responses in Monash University and discovered that many students were unable to apply the relevant concepts to explain certain given situations. Does this mean that students have not understood the concepts that are presented to them in class? In order to answer this question, research into students' understanding of science concepts becomes important.

Aim of Study

This study examines the school science topic of 'light and sight' with the intention of understanding the complexities associated with students' concept formation. It also aims to find out whether gender differences exist in the way students understand events involving light and sight.

Background of Study

A major goal of science instruction in the secondary school is the development of conceptual understanding. The aim is not about arriving at the correct answer to a problem as teachers are often distracted to believe, but about the attainment of understanding of the relationship which connects the answer to the problem (Butts, 1963). As Butts and Garone (1960) argue, the attainment of understanding of the relationship is the development of concept. This concept development is the dynamic interaction of students' personal experience with the

environment to form a symbolic construct which can be used to explain other similar phenomena. This symbolic construct becomes part of a cognitive structure that guides a student in a new situation.

Concept development is related to students' reasoning patterns. Piaget's developmental stages have underlined the different discrete stages of intellectual development which students move through from birth to maturity. The first two stages are called Sensory-motor and Ikonic. They are usually completed when a child is about seven years old. The next two stages are called Concrete Symbolic and Formal.

Piaget has suggested that the process whereby individuals move from one stage to the next to four factors: maturation, experience with physical environment, social transmission and equilibration. The last term refers to an internal mental process in which new experiences are combined with prior expectations to generate new logical operations.

One has to describe the reasoning of a student whose development has reached each of the stages in order to make the stage concept useful. This description has been stated by Piaget in terms of the mental operations the student uses when facing certain problems. It is from the research of Piaget that certain rules have been formulated for identifying reasoning patterns as belonging to concrete or to formal thought.

In Piaget's theory, cognitive development proceeds in discrete stages, each stage being defined in terms of a logical structure. Many researches such as Case (1985), Halford (1985), Mounoud (1986), Fischer and Silvern (1985), and Demetriou and Efklides (1987) agree with Piaget that stages should exist in some form. Since Piaget had explained clearly the significance of each stage, his theory of cognitive development has become the basis for other theories to develop. In this case, it lays the foundation for the Structure of Observed Learning Outcomes (SOLO) Taxonomy to build on.

The SOLO Model

The five modes of cognitive functioning (Sensory-motor, Ikonic, Concrete Symbolic, Formal and Post-Formal) and the existence of levels form the basis of a hierarchy. This postulated hierarchy (Collis & Biggs, 1989) reflects a consistent sequence or learning cycle that is generalizable to a large variety of tasks. Collis & Biggs (1989) believe that learners progress gradually towards matured learners as there is an increase in the structural complexity of their responses. The SOLO Taxonomy may be used to evaluate learning quality or to set curriculum objectives. In addition to this, it allows researchers to study the changes across levels which are closely related to the broad framework of cognitive theory.

In order to probe further into students' understanding of science concepts with respect to seeing, a Students' Seeing Framework (SSF) was developed by Jones et al. (1995) to work hand in hand with the SOLO Taxonomy. They constructed a framework for seeing based on three fundamental components called 'primitives' involving light, the eye and the object. This framework involved building connections between each pair of the 3 primitives, i.e. between light and eye (L/E), eye and object (E/O) and light and object (L/O). The primitives could be held

by individuals as defined by the SOLO Taxonomy. The SOLO Taxonomy provided them with a theoretical basis for hypothesising that each set of connections is developed in a unique order e.g. L/O 1 precedes L/O 2 and L/O 2 precedes L/O 3. If a students has fully understood the relationship between light and object, he will be deemed to possess the L/O 3 primitive. L/O 2 is meant for students with partial understanding and L/O 1 is for those with little understanding.

In the 1980s, the SOLO Taxonomy and the SSF were seldom used as tools to understand differences in the way students formed concepts about any science topic. Reap and Cavallo (1992) made use of the assessment technique known as 'mental modelling' to ascertain whether gender differences could be one of the factors related to students' acquisition of science concepts. They assessed 140 10th grade high school students from New York State and found that there were significant gender differences. Male students scored better than the female students in the understanding of science concepts.

Smail and Kelly (1984) used a series of multiple choice, structured and essay questions to assess a total of 2065 secondary school students from 10 different schools in England. They wanted to find out whether there were gender differences in science knowledge, spatial ability and mechanical reasoning. They discovered that female and male students were approximately equal in science knowledge. However, males did better than females in physical sciences, and on tests involving spatial ability and mechanical reasoning.

Study Sample

A total of 237 Secondary 3 and 4 (Grades 9 and 10) students were selected from six Singapore schools. Of the six schools, one was an independent school, two were government-aided schools, two were government schools and one autonomous school. To approximately represent the mix of schools in Singapore, a stratified opportunity sampling was carried out to select the schools. All the students had learnt about the topic 'light' in their Secondary 1 and 2 science curriculum.

Method of Study

An open-ended questionnaire consisting of 9 questions about 'light and sight' was used in this study. The questions were adapted from the questionnaire used by Jones et al. (1995) to suit the situation in Singapore. Certain words and sentences were either replaced or altered to avoid a cultural bias. This was to ensure students could respond freely to the questions. The richness of their responses is used as an indicator of the complexity of their understanding of science concepts tested.

Results and Discussion

TABLE 1
One-way Anova for 3 pairs of Primitives on Secondary 3 & 4 students

	Sample	F Ratio	Prob > F
Secondary 3	140	23.97	0.0000 **
Secondary 4	97	7.97	0.0007 *
Comb(Sec 3 & 4)	237	28.32	0.0000 **

* $p < 0.001$; ** $p < 0.0001$

Table 1 reports the results of a One-way Analysis of variance of students' responses with respect to the 3 pairs of primitives i.e. Light/Eye (L/E) , Eye/Object (E/O) and Light/Object (L/O). Each primitive connects any two of the reference points (Light, Eye and Object) in the Students' Seeing Framework. If a student shows that he has fully understood a science concept, he should score well in each pair of primitive. The aggregate score for the 3 pairs of primitives is used as an indication of depth of students' understanding of the concept involved. For instance, if a students shows that he has fully understood the relationship between any two of the three reference points (Light, Eye and Object), he is awarded 3 points. 2 points are awarded for partial understanding and 1 point is awarded for little understanding. Students who do not understand the relationship at all will not be awarded any point.

A comparison students' performance in Table 1 reveals that there are significant differences in the scores of students across primitives at the Secondary 3 and 4 levels. Even the combine score for both levels also show a significant difference across primitives.

A Bartlett's Chi-square test of equal variances for the Secondary 3 and 4 students is carried out. A low Bartlett's test value will imply that One-way Anova's equal-variance assumption is implausible. In other words, the Anova (F test) results could be untrustworthy. The Bartlett's test values for the One-way Anova obtained for each level are shown in Table 2.

Table 2
Bartlett's Chi-square Test of Equal Variance for Secondary 3 & 4 students

	Bartlett's Test Value
Secondary 3	0.240
Secondary 4	0.731
Combine (Sec 3 & 4)	0.692

Table 3
Multiple Comparison Procedure (Scheffe) for 3 pairs of Primitives

From Table 2, the Bartlett's test value obtained from the One-way Anova for the scores across the 3 pairs of primitives in the Secondary 4 is very high (0.731) . This confirms the significant difference between the means among the 3 pairs of primitives. The Bartlett's test value for the Secondary 3 level was much lower than that of the Secondary 4 level. The test value for the combine (Sec 3 & 4) score is 0.692 .

Hence, the combine (Sec 3 & 4) score for the One-way Anova (F test) should be reliable.

Table 3 reports the results of a Multiple Comparison Procedure (Scheffe) of students' responses with respect to the 3 pairs of primitives. This analysis is a follow-up of the One-way Anova done earlier. It allows a closer examination of the mean scores obtained from each pair of primitive for both Secondary 3 and 4 levels. In the Secondary 3 level, there is a significant difference between the L/E primitive and the E/O primitive. There is, however, no significant difference between the L/E primitive and the L/O primitive. There is a significance difference between the E/O primitive and the L/O primitive. The same trend reappears in the Secondary 4 level. Hence, a significant difference in the L/E and E/O primitives and in the E/O and L/O primitives would be expected.

Table 4 shows the mean scores of the 3 pairs of primitives. The mean score for the E/O primitive is the weakest among the 3 pairs of primitive in both Secondary 3 and 4 levels. This would mean that many students were unable to understand the relationship between eye and the object. They did not understand the fact that light rays must fall on the object before they were reflected back into our eyes.

Table 4
Mean Scores of 3 pairs of Primitives

Group		Mean	SD
Secondary 3	L/E	59.19	17.66
	E/O	36.42	13.54
	L/O	59.69	17.36
Secondary 4	L/E	50.63	21.67
	E/O	33.04	22.48
	L/O	54.71	19.31
Combine (Sec 3 & 4)	L/E	55.52	19.78
	E/O	34.97	17.85
	L/O	57.56	18.24

Table 5
Kruskal-Wallis Test on 3 pairs of Primitives for Secondary 3 & 4 students

	Chi-square Value	df	P
Secondary 3	35.80	2	0.0001 *
Secondary 4	16.15	2	0.0003 *
Combine (Sec 3 & 4)	43.42	2	0.0001 *

* $p < 0.001$

Table 5 shows that the results obtained from a Kruskal-Wallis test. The test provides a non-parametric alternative to analyse the results obtained from One-way Anova. The Kruskal-Wallis test checks the null hypothesis of identical population medians. If the p- value of this test is very close to the p-value obtained in the One-way Anova, then the Anova's equal variance or normality assumption should not be doubted. In other words, there would not be problems with outliers and the assumption of similar-shaped distributions within each group of primitive should hold. In this case, the p-value for the Kruskal-Wallis test in the Secondary 3 level was 0.0001. This value matched well with the p-value (0.0000) obtained for the One-way Anova. The value obtained for the Kruskal-Wallis test (p=0.0003) agreed with that of the value obtained by One-way Anova (p=0.0007) in the Secondary 4 level.

Table 6 shows that Secondary 3 male students performed better than the females in three questions (Questions 1, 2 and 5). However, the Secondary 4 female students outperformed their counterpart in seven questions (Questions 1, 3, 4, 5, 7, 8 and 9). The reversal in gender difference is quite spectacular.

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Table 6
Gender differences for each question

	Question	Mean/Sd	Male	Female	t test
Secondary 3	1	Mean	6.40	5.21	3.19*
		SD	1.90	2.50	
	2	Mean	5.88	4.95	2.36*
		SD	2.04	2.56	
	3	Mean	3.08	3.02	0.25
		SD	1.72	1.77	
	4	Mean	5.47	5.42	0.15
		SD	1.92	1.91	
	5	Mean	4.51	3.52	2.63*
		SD	2.32	2.02	
	6	Mean	4.42	3.61	1.91
		SD	2.60	2.23	
	7	Mean	3.05	2.46	1.42
		SD	2.51	2.28	
	8	Mean	4.67	5.23	1.40
		SD	2.31	2.28	
	9	Mean	3.70	4.46	1.70
		SD	2.66	2.47	
Secondary 4	1	Mean	5.49	7.06	2.97*
		SD	2.55	2.25	
	2	Mean	5.44	6.41	1.75
		SD	2.49	2.69	
	3	Mean	2.71	4.56	4.46***
		SD	1.80	2.17	
	4	Mean	4.21	5.88	2.48*
		SD	3.09	3.17	
	5	Mean	3.38	4.97	2.33*
		SD	3.17	3.15	
	6	Mean	3.53	4.75	1.70
		SD	3.21	3.60	
	7	Mean	2.74	5.06	3.50**
		SD	3.08	3.08	
	8	Mean	3.61	4.81	2.22*
		SD	2.55	2.46	
	9	Mean	3.06	5.00	3.26**
		SD	2.62	3.05	

*p< 0.05 ; **p< 0.01; ***p< 0.001

There are several plausible reasons why Secondary 3 males did better than the females in Question 1. Boys generally enjoyed blackouts as compared to the females. The latter found blackouts to be more disconcerting and disorienting. They preferred not to be subjected to such unpleasant experience. Evidence for this shows up in the responses female students provided.

"It's too frightening to remember anything in the dark." (F006S3)
(The above code refers to the sixth female student in Secondary 3 level)

"I don't think anything can be done in the dark." (F108S3)

Many Secondary 3 male students were able to perform better in Question 2 because they answered to the point. They would usually explain how light rays were reflected off the mirror to reach their eyes.

"Her body reflects light off the mirror. Thus, her image could be seen on the mirror."
(M075S3)

Some Secondary 3 female students, however, concentrated on the beauty of the image or the shape of the mirror.

"I don't think I will look nice with this square mirror." (F084S3)

In Question 5, the Secondary 3 male students outperformed the female students because most male students were able to describe in detail how a person could see the moon on the water.

"Because the moon's image is reflected off the water. The light rays from the moon hit the water and are reflected off the water, forming an image of the moon on the water." (M081S3)

The female students were generally unable to provide enough details to explain the reflection of the moon.

"It is due to reflection. The image is not clear." (F054S3)

The trend in Secondary 4 level was totally different. The girls outperformed the boys in almost every question. This may be attributed to the fact that the females were more serious in the way they answered the questions . They took every opportunity to practise before sitting for the national examination (GCE 'O' Level). The male students, however, were less enthusiastic in doing an exercise which was unrelated to their national examination. This could be clearly seen in the following examples.

"Light rays are not reflected when the train enters the tunnel." (M112S4)

"The background of the door is black." (M090S4)

The results at the Secondary 4 level shows that female students performed better than their male counterparts. This finding seems to contradict what Reap and Cavallo (1992) had found in which male students scored better in the understanding of science concepts. Smail and Kelly (1984) reported similarly that male students performed better in physical sciences.

We attribute the better performance of the female students in the study sample to the fact that they were more careful in answering the questions. This was supported by the examples cited earlier.

Implications of the Study

This study has shown that many students do not comprehend the relationship between eye and object fully. From the teachers' stand-point, there is a need to examine students' misconceptions from prior their experiences and correct them immediately. Garnett and Hackling (1995) suggested some useful ways to ameliorate the problem. By posing relevant questions to students, it is possible to test students' attainment and mastery of knowledge involving the specific concept. They also emphasized the importance of correcting misconception promptly. In other words, on the spot follow-up error analysis of alternative conceptions is crucial in order that misconceptions do not take root. With the pressure of time, teachers usually do not have the opportunity to back track to correct students' misconceptions. In addition to this, Garnett and Hackling (1995) suggest that teachers get their students to explain what they have learnt by citing appropriate examples which are relevant to the specific concept. Students should also be encouraged to apply the concepts learnt in daily problem-solving situations as opportunities arise.

Another outcome of this study that needs to be highlighted is the time that female students take to grasp the concepts of light. Table 6 shows that Secondary 4 female students did better than their male counterparts. However, the Secondary 3 male students fared better than the female students. Yeoh and Tan (1987) confirmed this after investigating the understanding of science concepts of 38,502 Secondary 3 students. It is apparent from the results of Table 6 that female students need more time to understand science concepts. In order for female students to catch up quickly with their male counterparts, Carroll (1963) suggested that they ought to be given the Opportunity-To-Learn (OTL). OTL is the amount of time allowed for learning. It is the actual amount of time spent on acquiring science

concepts. Yeoh and Tan (1987) pointed out that many teachers tend to neglect female students who are usually deemed to be weak in science. If teachers give the female students opportunities to be directly involved in science practical lessons and discussions, they are likely to understand science concepts faster.

References

Butts, D. P. (1963). The Degree to which Children Conceptualize from Science
Experience. Journal of Research in Science Teaching, 1, 135-143.

Carroll, J. B. (1963). A Model of School Learning. Teachers College Record,
64, 723-733.

Case, R. (1985). Cognitive Development. New York: Academic Press.

Collis, K. F. & Biggs, J. B. (1989). Multimodal Learning and the Quality of
Intelligent Behaviour, in H. Rowe (Ed). Intelligence: Reconceptualization
and Measurement. Hillsdale. N.S.W..

Demetriou, A. & Efklides, A. (1987). Experiential Structuralism and Neo-Piagetian
Theories: Towards an Integrated Model. International Journal of Psychology,
22, 679-728.

Fischer, K. & Silvern, L. (1985). Stages and Individual Differences in Cognitive
Development. Annual Review of Psychology, 36, 613-618.

Garnett, P. J. & Hackling, M. W. (1995). Students' Alternative Conceptions in Chemistry.
Studies in Science, 25, 69-95.

Garone, J. (1960). Children's Scientific Concept Development. Science Education,
44, 104-107.

Gunstone, R. & White, R. T. (1981). Understanding Gravity. Science Education,
65(3), 291-299.

Halford, G. S. (1982). The Development of Thought. Hillsdale. N. J.: Lawrence
Erlbaum Associates.

Jones, B. L., Collis, K. F., Watson, J. M., Sprod, T. J. & Fraser, S. P. (1995).
Building an Understanding of Vision: Mapping Development on a Students'

Seeing Framework. Paper presented at the 26th ASERA Conference, Bendigo.

Mounoud, P. (1986). Similarities between Developmental Sequences at different age

periods. Norwood. N. J.: Ablex.

Ormerod, M. B. & Wood, C. (1983). A Comparative study of three methods

of measuring
the attitudes to science of 10 to 11 year old pupils. European Journal of Science
Education, 5, 77-86.

Reap, M. A. & Cavallo, A. L. (1992). Students' Meaningful Understanding of Science
Concepts: Gender Differences. Paper presented at the Annual Conference of the
National Association Research in Science Teaching, Boston.

Smail, B. & Kelly, A. (1984). Sex Differences in Science and Technology among eleven
old school children. Research in Science and Technological Education, 2.

Yeoh, O. C. & Tan, Y. K. (1987). A Cross-Sectional perspective on Science Performance
in Singapore. Singapore Journal of Education, 8, 23-54.