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AUTHOR Young, Deidra J.
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ABSTRACT

In 1983/84, the International Association for the Evaluation of Educational Achievement (IEA) conducted their second international science study to investigate two factors related to student achievement in science: (1) the relationship between students' reported perceptions of the science learning environment and their science achievement; and (2) the effect of various science learning environment scales on gender and socioeconomic differences in science achievement. Participants included 10-year-old, 14-year-old (focus in this report), and grade 12 students from 12 of the 24 countries/educational systems in the original study. Although the countries appeared incomparable in terms of their educational systems, results revealed that one commonality that exists between all countries examined is an increased practical work component in science lessons associated with improved science achievement by students. Furthermore, the variability found in science achievement outcomes from school to school supports the assertion that the student's learning environment has an effect on achievement outcomes. The test instrument for 14-year-old students is appended. (ZWH)

The Effect of the Science Learning Environment on Science Achievement and Equity

Deidra J. Young
Science and Mathematics Education Centre
Curtin University of Technology
Perth, Western Australia

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Background to the Second International Science Study

The International Association for the Evaluation of Educational Achievement (IEA) conducted a study of science achievement in 19 countries in 1970 (First International Science Study) and in 24 countries/educational systems in 1983/84 (Second International Science Study). The IEA is a voluntary research organisation and did not select countries to participate in its studies. Rather, research centres in each country elected to participate as long as they had the experience and financial resources to conduct and fund the study. The participating countries planned the study on a cooperative basis, taking care to ensure that the test instruments were fair for all participating countries in terms of curriculum and culture. Additionally, care was taken that all student background questions, attitude scales and other measures were comparable cross-nationally.

The Second International Science Study (SISS) sampled students from three age groups: 10-year-old, 14-year-old and year 12 students (Rosier & Keeves, 1991; Postlethwaite & Wiley, 1992; Keeves, 1992). For the secondary analyses reported in this paper, the 14-year-old student data were analysed. The complex sample design used in this study meant that the normal assumptions of simple random sampling could not be made and therefore that conventional statistical significance tests might not be valid. That is, in this study, schools were randomly selected within each region/state and intact classes selected from within these schools. However, for the Australian, English and Italian studies, students were randomly selected from within the school.

The research reported in this paper focused upon data from 12 countries from the Second International Science Study, specifically the 14-year-old students (Population 2) in Australia, England, Finland, Hungary, Italy, Japan, Korea, The Philippines, Singapore, Sweden, Thailand and the United States of America. In these countries, most 14-year-old students provided information regarding their socioeconomic status which was considered important for these analyses and this study. Additionally, some of these countries have already been investigated by Keeves (1992) and Kotte (1992), which was useful for this study.

The purpose of this study was to investigate the relationship between the student's reported perceptions of the science learning environment and their science achievement. This relationship was analysed using multilevel modelling for each of the 12 countries. Additionally, this study examined the effect of these science learning environment scales on gender and socioeconomic differences in science achievement.

Classroom Environment Research

International research into the conceptualisation, measurement and investigation of perceptions of psychosocial characteristics of the learning environment of classrooms at the primary, secondary and higher education levels have used classroom environment instruments both as predictor and criterion variables in a variety of research studies (Chavez, 1984; Fraser, 1986, 1989; Fraser, in press; Fraser & Walberg, 1991; MacAuley, 1990).

The use of student perceptions of classroom environment as predictor variables in several different countries has established consistent relationships between the nature of the classroom environment and various student cognitive and affective outcomes (Fraser, 1986; Haertel, Walberg & Haertel, 1981). In addition, research involving a person-environment fit perspective has shown that students achieve better where there is greater congruence between the actual classroom environment and that preferred by students (Fraser & Fisher, 1983).

In this analysis of the Second International Science Study data, the students' reported perceptions of their science learning environments were investigated as predictors of their science achievement.

Gender and Socioeconomic Equity

Recently the Australian Education Council released a report into Young People's Participation in Post-compulsory Education and Training chaired by T.B. Finn (Australian Education Council, 1991). The Finn report, as it is now commonly called, classified as deeply disadvantaged in relation to their educational participation the following groups of young people: Aboriginal youth, some non-English speaking background young people, some young women, the homeless, the long-term unemployed, those in isolated communities, young offenders and disabled young people. In addition, the Finn Report highlighted the imbalance of courses taken by males and females, with young women participating to a lesser extent than men in courses based on physical sciences and advanced mathematics. Similarly, young people from poor socioeconomic backgrounds tended to have lower participation rates than others in these same courses. In order to address the problems faced by the disadvantaged young people in Australia, highlighted by the Finn report (Australian Education Council, 1991) and reiterated by the Mayer report (Australian Education Council, 1992, pp. 45-46), this research study focused on how the science learning environment can influence outcomes in science achievement.

The significance of this study was related to the high quality and dependability of the findings, because this research was based upon student data from 12 countries collected in a systematic manner and collated by researchers at the University of Hamburg. The implications of research which can identify those learning environment factors which enhance achievement in science was highlighted by the Commonwealth Schools Commission (1987). If those factors are found to be associated with gender and socioeconomic equity, then the importance of this study is even greater for educational organizations.

The Sample and Target Populations

While there were 24 countries/educational systems participating in the Second International Science Study, these analyses focused upon 12 countries which had measured socioeconomic status in a valid way. These students were more likely to represent most students in this age group due to compulsory schooling at this age. These students were at the lower secondary school level in most countries, and in many countries they were at the last point in the school system where 100 percent of an age group is still in compulsory schooling. The maximum age for compulsory schooling in the 12 countries under investigation ranged from the age of 13 to 17 years. Also, this sample represented 98 to 99 percent of the age cohort in school for all 12 countries, except Thailand which was 32 percent of the age cohort in school. Clearly, in this study, Thailand had larger differences in their educational system, when compared with the other eleven countries. For Hungary, Italy and Thailand, there was a marked increase in retention of students at school since the First International Science Study in 1969.

Science Learning Environment

The students' perceptions of the science learning environment are likely to influence their learning, irrespective of the actual facilities provided and the teacher's strategies used to teach science. Keeves and Dryden (1992, pp. 187-207) described teaching and learning in science classrooms from three general perspectives. First, there is the perspective of teaching involving imparting information (teacher-directed learning or transmission of knowledge). Secondly, there is the perspective of teaching as meeting the needs of the students (student participation). Thirdly, there is the scientific perspective in which the learning of science is seen as a process of investigation (practical work and open-ended inquiry learning). These three views of science learning were termed 'instruction', 'participation' and 'investigation' by Keeves and Dryden and reflect a learning environment which is passive, sharing and active, respectively.

In this study, the three descriptive scales associated with views of science teaching and learning were defined by Keeves and Dryden as follows:

1. *Student Participation*: The student reports being able to make a choice of science topics to be studied, doing field work outside the classroom, being permitted to make up problems and working out methods and solutions to problems. In addition, the teacher uses the students' ideas and suggestions in planning science lessons.

2. *Teacher Directed Learning*: The student reports that the science teacher starts lessons with an explanation of work to be covered and a reminder of what was taught in previous lessons, finishes with a summary, explains the relevance of the work taught, conducts demonstration experiments and helps students with difficulties in learning science.

3. *Practical Work*: The student reports doing practical work in small groups during science lessons, with written instructions or with instructions given by the teacher. Reports of practical work are written up for homework.

Students were asked to give their views by responding to statements, as described in Table 1, and by indicating whether they considered that the activity involved in each statement 'often' takes place, 'sometimes' takes place or 'never' takes place (coded 1, 0.5 and 0 respectively). The scale score for *Student Participation*, *Teacher Directed Learning* and *Practical Work* were calculated by taking the mean of the items, so that the scales ranged in value from 0 to 1. If a particular student's item scores were missing for more than 20% of the items in a scale, then the scale was set to missing for that student.

Table 1. The Items in Science Learning Environment scales for 14-Year-Old Students, 1983/84.

Student Participation

1. We are allowed to make our own choice of science topics to study.
2. The teacher uses our ideas and suggestions when planning science lessons.
3. We do field work outside the classroom as part of our science lessons.
4. In our practical work, we make up our own problems and then the teacher helps us to plan experiments to solve them.
5. When we do experiments, the teacher gives us problems to solve and then leaves us to work out our own methods and solutions.
6. In our practical work, we make up our own problems and work out our own methods to investigate the problems.

Teacher Directed Learning

1. At the start of each science lesson, the teacher reminds us about the work we covered during previous lessons.
2. At the start of each science lesson, the teacher explains the work we have to cover during the lesson.
3. At the end of each science lesson, the teacher gives a summary of what was taught in the lesson.
4. The teacher does demonstrations to help explain scientific ideas.
5. The teacher explains how the science we do is relevant to our own lives.
6. The science teacher helps students who have difficulties with learning science.

Practical Work

1. For science homework, we write up reports of our laboratory and practical work.
2. We do practical work (experiments) as part of our science lessons.
3. The science class breaks into small groups of students to do practical work (experiments).
4. When we do experiments, the teacher gives us instruction about what to do.
5. When we do an experiment, we use a book or other written instructions to show us how to do it.

Science Achievement

The science achievement test for 14-year-old students consisted of 30 common core science test items taken by all students and 40 rotated test items (4 tests were available), with students being required to take two of the rotated tests (20 items). Therefore, the maximum possible score was 50, although there was total of 70 science test items available. These science test items were multiple-choice only, although they did cover a range of cognitive abilities and science content areas (see Appendix A for the common core test instrument). The estimated mean science achievement score for each country is presented in Table 2, along with the standard errors of measurement, intra-class correlations and sample sizes by school and student. These are discussed further in a later section. Overall, the sample size involved in the present study was 51,014 students in 1909 schools across 12 countries.

Methodology

Because these datasets consisted of students residing inside schools, there was bound to be a certain amount of differences between schools. While schools might form part of the same educational system within a country, they could have entirely different cultures, curricula and organisational environments. In addition, students within the same classroom can experience different learning environments from each other depending upon the teacher's style, characteristics and the characteristics of the other students in the classroom. There are many factors which can influence student performance, both at home and at school, as well as the student's own internal influences. In this study, we chose to examine the students' perceptions of their own learning environment in science classes and how these perceptions related to their achievement in science. In order to separate the school level differences from the student differences in science achievement, we used a methodology usually referred to as multilevel modelling or Hierarchical Linear Modelling (HLM).

Most educational research involves students who receive schooling in classrooms located within schools, within school districts, within states, etc. This grouping of students, classes and schools occurs in a hierarchical order, with each group influencing the members of the group in thought and behaviour. The nature of these hierarchical structures produces multilevel data. The amount of variation in estimates of variables affecting academic achievement across different levels of analysis cannot be ignored by serious educational researchers. In particular, the socioeconomic status of the student and of the school have been shown to consistently account for a large amount of variation in achievement both at the school level and at the student level of analysis. Traditional linear models on which most researchers rely require the assumption that errors are independent, yet most subjects are 'nested' within classrooms, schools, districts, states and countries so that responses within groups are group dependent. To ignore the nested structure of this type of data ultimately will give rise to problems of aggregation bias and imprecision (Cronbach, 1976, Burstein, 1980, Raudenbush, 1988).

The Hierarchical Linear Model (HLM) provides an integrated strategy for handling problems such as aggregation bias in standard error estimates and erroneous probability values in hypothesis testing of school effects. For this study, HLM was chosen as the model most appropriate to study school and student effects relating to science achievement, and Bryk, Raudenbush, Seltzer and Congdon's program (1989) was selected as the computer package most suited to analyse the large amount of data in SISS. The use of the HLM in order to investigate the influence of the organisational structure of the school on student performance has been documented by Bryk and Raudenbush (1989, pp. 159-204), Lee and Bryk (1989) and Raudenbush and Bryk (1986).

The present study sought to examine the role of the science learning environment in explaining student differences in science achievement. Research on school effects which analysed data at the individual student level, with the assumption that classrooms and schools affect students equally, can be misleading when the effects vary among individuals and their contexts (Bryk & Raudenbush, 1987). Ordinary least squares analysis provides information about the total variance, but can only decompose this total variance into the between- and within-school effects. The between-school effect could be influenced by school level variables, such as the affluence of the school. Research which endeavours to explain variations in student outcomes by first decomposing observed relationships into between- and within-school components have used the hierarchical linear model to examine the effects of the home and the school on student achievement (Young, 1991a, 1991b, in press; Young & Fraser, 1993, in press), but this study focuses on the effect of the science learning environment.

Results and Discussion

The partitioning of variance in science achievement among students into the within- and between-school components was achieved using the HLM computer package (Version 3.01, Scientific Software, April 1992; Bryk, Raudenbush, Seltzer & Congdon, 1989). A random mean science achievement estimate was specified for the within-school model, centred around the grand mean for this model:

$$Science_{ij} = \beta_{0j} + R_{ij} \qquad \text{Equation 1}$$

where $i = 1, \ldots, n_j$ students in school j, $j = 1, \ldots, J$ schools, $Science_{ij}$ represents the science achievement of student i in school j, β_{0j} represents the mean science achievement for students in school j and R_{ij} represents random error of student i in school j. At the school level, the school mean science achievement is a function of the grand mean, γ_{00}, with random error, μ_{0j}:

$$\beta_{0j} = \gamma_{00} + \mu_{0j} \qquad \text{Equation 2}$$

The grand means in these analyses, along with their statistical significance, are presented in Table 2 for all 12 countries. In these analyses of the random model for Australia, the variance in science achievement was found to be 16 percent at the school level ($\hat{\tau}_{00} = \text{var}(\mu_{0j}) \approx 10.12$), while 84 percent of the variance was related to student level differences $\hat{\sigma}^2 = \text{var}(r_{ij}) \approx 52.56$); these estimates indicate that most of the variation in science achievement for Australia was at the student level, although a substantial proportion was between schools. Similar results were found for England, Hungary and Italy, with 14, 26 and 25 percent, respectively, of the total unexplained variance found to be at the school level. However, there were some differences noted for other countries. Finland, Japan and Sweden had very low intra-class correlations, indicating that there were few school differences in mean science achievement. This either could be a reflection of these countries' educational systems or of the sample selected for the SISS study. That is, their schools could be very similar or the sample of schools selected could be very similar.

On the other hand, Hungary, Italy, The Philippines, Thailand and the United States had much higher intra-class correlations (0.26, 0.25, 0.48, 0.25 and 0.34, respectively). That is, their schools varied appreciably in average student achievement in science. Again, this could be a reflection of a much better, more varied sample of schools were selected for this study, or simply that these countries have a more inequitable educational system. That is, some schools simply have higher student achievement, while other schools have much lower student achievement. The reasons for this are beyond the scope of this paper. However, it is important that these differences between schools are kept in perspective when comparing countries.

Student Background Variables

Before investigating the effect of the classroom environment on student achievement, four student level variables were examined. The purpose of this analysis was to estimate the effect of the these generally unalterable variables on achievement and the power they have to explain student differences. This type of analysis is often referred to as the compositional model (see Bryk & Raudenbush, 1992, p. 89). The results of these analyses are presented in the *Compositional Model* section of Table 2.

Table 2. Estimated Effects of Student Background and the Science Learning Environment on Science Achievement for 12 Countries and 14-Year-Old Students, 1983/84.

	Australia	*England*	*Finland*	*Hungary*	*Italy*	*Japan*	*Korea*	*The Philippines*	*Singapore*	*Sweden*	*Thailand*	*USA*
Number of Students	4917	2547	2546	2515	4622	7610	4522	10871	4430	1245	3231	1958
Number of Schools	233	120	89	98	222	199	189	268	183	137	83	88
Grand mean achievement, β_{00}	30.06	27.14	30.14	35.19	26.03	33.34	18.05	11.37	16.70	34.38	27.70	30.98
Proportion of variance between schools (%)	16	14	5	26	25	4	15	48	56	7	25	34
Compositional Model												
Grand mean achievement, β_{00}	30.15**	27.08**	30.14**	35.23**	26.02**	33.40**	18.03**	11.38**	16.67**	34.20**	27.68**	31.08**
Socioeconomic Status, β_{10}	1.03**	1.04**	.79	1.55**	.92**	1.64**	.34**	.29**	.10*	1.71**	.51**	.64**
Gender, β_{20}	-2.69**	-4.71**	-1.98**	-2.21**	-3.18**	-1.93**	-2.21**	-.69**	-1.99**	-3.40**	-3.28**	-4.14**
Homework Effort, β_{30}	2.00**	3.03**	-.10	.82**	1.22**	1.19**	.46**	.16**	.26**	1.04*	.87**	.86**
Science Attitude, β_{40}	-	-	2.07**	-.52	.24	2.51**	1.40**	.27**	.57**	2.43**	1.81**	2.12**
Proportion of variance in achievement explained by compositional model (%)	12	20	8	12	11	16	7	5	7	13	12	14
Science Learning Environment Model												
Grand mean achievement, β_{00}												
Intercept, γ_{00}	27.47**	23.27**	25.04**	16.80**	19.01**	29.30**	21.36**	3.76*	7.52**	27.09**	17.55**	25.20**
Socioeconomic Status, γ_{01}	1.71**	.77	1.86**	3.39**	3.24**	.50	.94**	1.20**	3.08**	.36	.26	2.22**
Student Participation, γ_{02}	-8.73**	-8.88*	-6.61	-9.97	-14.56**	-4.17	-1.12	-7.39**	-14.10**	-5.89	-15.04**	-13.57**
Teacher Directed Learning, γ_{03}	-.84	-4.32	-4.06	16.96*	4.65	4.25**	-7.88*	9.67**	-5.46*	-3.30	-4.38	-1.66
Practical Work, γ_{04}	1.52	9.34**	7.72**	2.76	6.89**	2.26	-.58	1.58	12.55**	12.60**	23.98**	9.00**
Socioeconomic Status, β_{10}												
Intercept, γ_{10}	1.00	3.25*	1.86	-.33	-2.35	.40	1.97*	.80*	.18	1.87	-.35	.43
Student Participation, γ_{11}	3.86**	2.66	3.05	2.99	1.45	3.30	-.67	-.74	-.01	1.25	1.04	3.15
Teacher Directed Learning, γ_{12}	2.18	-4.46*	-5.27*	.97	6.29*	-.86	-1.58	-.22	-.35	2.76	.53	-.83
Practical Work, γ_{13}	-3.12**	-.19	1.20	-.29	-3.43**	1.10	-.86	-.06	-.11	-2.76	.01	-.05
Gender, β_{20}												
Intercept, γ_{20}	-1.23	-6.84	-3.90	-4.71	-9.69**	-2.46	-.20	.92	1.00	4.35	.54	-2.84
Socioeconomic Status, γ_{21}	-.85*	.97	.27	-.72	.41	.32	.03	-.76**	-1.25**	.31	-.39	.39
Student Participation, γ_{22}	-2.47	10.50	8.97	-15.61*	7.39**	-6.03	-1.62	.20	.50	.12	-1.75	-.50
Teacher Directed Learning, γ_{23}	1.39	-7.54	10.33	.70	4.61	-.24	-4.14	-.81	-.49	.89	2.99	-3.09
Practical Work, γ_{24}	.51	3.68	-10.28*	15.83**	-2.59	1.78	3.19	.61	-.47	-11.22	-5.38	.03
Homework Effort, β_{30}												
Intercept, γ_{30}	1.85**	2.76**	-.12	.84**	1.21**	1.18**	.46**	.16**	.26**	.93*	.86**	.81**
Attitude to Science, β_{40}												
Intercept, γ_{40}	-	-	2.07**	-	-	2.50**	1.39**	.25**	.57**	2.28**	1.87**	2.21**
Total between schools variance: var(μ_{0j})	10.12	8.28	2.45	14.85	14.13	2.69	3.15	10.36	13.25	6.18	10.07	21.62
Compositional model: var(μ_{0j})	4.85	3.67	2.01	12.16	10.93	1.18	2.14	9.44	11.25	5.73	8.67	16.78
Science Learning Environment model: (μ_{0j})	3.01	2.78	1.42	9.03	8.32	1.03	1.74	6.70	4.03	5.05	5.45	8.84
Incremental proportion of total between schools variance in mean achievement explained by the Science Learning Environment model (%)	18	24	29	26	24	13	19	29	64	12	37	47

** $p<.01$
* $p<.05$

For the purposes of this study, the four student level variables were *socioeconomic status*, *gender*, *homework effort* and *attitude to science*. The *socioeconomic status* of the student was measured by the father's occupation on a four point scale with higher numbers indicating more professional occupations and lower numbers indicating more unskilled and labouring type of occupations. For many countries this data was not collected. In this analysis, Japan did not collect father's occupation, so the number of books in the home was used as a alternative measure. Both the father's occupation and number of books in the home are highly correlated with each other and with science achievement. Generally, more positive effects indicate that students from higher socioeconomic backgrounds outperformed students from lower socioeconomic backgrounds.

Gender was measured by the sex of the student with males coded 1 and females coded 2. More positive effects indicated that female science achievement was favoured, while more negative effects were related to improved male science achievement.

Homework effort was measured by the student's reported time spent on homework per week in hours. Positive effects reflected an expected effect of student's who spent more time on homework having higher achievement. Of course, students of higher achievement would be expected to spend more time on homework.

The final student variable examined was the student's *attitude towards science*. This scale consisted of a number of items using a likert response set asking the student about their feelings about and attitude towards science in general and how beneficial science is to them.

Analysis of the Compositional Model

The Hierarchical Linear Model (HLM) used to investigate the student level variables is presented below in equation 3, with results found in Table 2. The four student level variables were centred around the grand mean for each variable. For example, the socioeconomic status of each student was centred around the grand mean socioeconomic status for the population ($SES_{ij} - \bar{X}_{ses}$). The beta coefficient for each student level variable indicates the strength of the effect of that variable on the student's science achievement score. Up to this point the hierarchical linear model resembles ordinary least squares or ordinary regression, with variability within schools only. The additional part of the hierarchical linear model involves allowing some of the variables to vary across schools, as well as varying within schools. For this study, two variables were allowed to vary across schools, along with the intercept. These were the intercept, socioeconomic status of the student and sex of the student. For these variables, the HLM model separated the unexplained variances at the school level for the intercept, SES and sex ($\hat{\tau}_{00} = var(\mu_{0j})$; $\hat{\tau}_{10} = var(\mu_{1j})$; $\hat{\tau}_{21} = var(\mu_{2j})$) from the student level ($\hat{\sigma}^2 = var(r_{ij})$). Each tau represents the unexplained variance at the between school level for each variable. The sigma squared represents the unexplained variance at the within school level (student level). The variables homework effort and attitude toward science were kept fixed for this study. That is, these unexplained variance for these variables were not allowed to vary from school to school, but rather were constrained to zero.

$$Science_{ij} = \beta_{0j} + \beta_{1j}(SES_{ij} - \bar{X}_{ses}) + \beta_{2j}(Sex_{ij} - \bar{X}_{sex}) + \beta_{3j}(Effort_{ij} - \bar{X}_{effort}) + \beta_{4j}(Attitude_{ij} - \bar{X}_{attitude}) + r_{ij}$$

$$\beta_{0j} = \gamma_{00} + \mu_{0j}$$
$$\beta_{1j} = \gamma_{10} + \mu_{1j}$$
$$\beta_{2j} = \gamma_{20} + \mu_{2j}$$

Equation 3

Results from Table 2 show that most of these variables had statistically significant effects across all 12 countries, with the exception of attitude towards science. Socioeconomic status of the student was statistically significant and positive in its effect on student science achievement for all countries other than Finland (see β_{10} in Table 2). Additionally, the differences in achievement between students from high and low socioeconomic backgrounds, called the SES slope, was significantly different across schools for some countries, notably England, Finland, Hungary, Italy, Japan, Thailand and USA (variance of μ_{1j}). The effect of this variation in the SES slope across schools indicates that the gap between performance of students from high and low SES backgrounds varied from school to school. While schools in Australia had a significant gap in performance, this gap or slope was the same across all schools. For other countries, such as England, the gap varied significantly. Some schools had a small difference in performance, while other schools had a large difference.

For the purposes of this analysis, all single-sex schools were removed to prevent confounding of the gender effect when only one sex was present in a school. When the gender slope was examined, the effect was strong and negative for every country (see β_{20} in Table 2). Because girls had a higher code (2) than boys (1), this negative effect indicates that boys are significantly advantaged for this outcome. This effect did vary in strength from country to country, with England and the United States revealing the greatest gender effects and Finland, the Philippines and Singapore revealing the smallest gender effects. When the gender slope was varied from school to school (the random effect), some countries showed negligible amounts of variability in the gender gap across schools (e.g., Australia's τ_{10} = .55), while other countries revealed a statistically significant τ (e.g., USA's τ_{10} = 5.47). For these countries with large and significant tau's (τ), gender differences were not consistent across schools, with some schools having large gender differences and some schools having small gender differences.

For some countries, the student's reported hours spent doing homework was significantly associated with their science achievement score. For these countries, students who spent more time on their homework tended to attain higher scores on this test (see β_{30} in Table 2).

Finally, the student's attitude towards science was measured using items on a likert scale and the effect of this variable estimated for each of the 12 countries. While the effect of science attitude was strong and positive for some countries, such as Finland, Japan, Sweden, Thailand and the United States, other countries revealed little or no effect, such as Australia and England. For Australia and England, the effect was so weak that the model could not be estimated with the variable present (see β_{40} in Table 2).

For the last two student level variables, homework effort and science attitude, the variability of these effects across schools was assumed to be negligible and constrained to zero. In Hierarchical Linear Modeling, this is called fixing the variance.

Science Learning Environment Model

For the purposes of this study, three science learning environment scales, *Student Participation*, *Teacher Directed Learning* and *Practical Work*, were modelled on science achievement at both the student and school levels. The four student level variables discussed previously were included, with socioeconomic status and gender being allowed to vary randomly across schools. Homework effort and attitude towards science were kept fixed across schools. In this HLM analysis, the three science learning scales were aggregated to the school/class level and their effects were modelled at the school level (Level-2). The HLM equation is provided below:

Level-1 Regression Model:

$$\text{Science}_{ij} = \beta_{0j} + \beta_{1j}(\text{SES}_{ij} - \bar{X}_{ses}) + \beta_{2j}(\text{Sex}_{ij} - \bar{X}_{sex}) + \beta_{3j}(\text{Effort}_{ij} - \bar{X}_{effort}) + \beta_{4j}(\text{Attitude}_{ij} - \bar{X}_{attitude}) + r_{ij}$$

Level-2 Random Slopes as Outcomes Models:

$$\beta_{0j} = \gamma_{00} + \gamma_{01}\text{AvSES} + \gamma_{02}\text{Stdirect} + \gamma_{03}\text{Tstruct} + \gamma_{04}\text{Pracwork} + \mu_{0j}$$
$$\beta_{1j} = \gamma_{10} + \gamma_{11}\text{Stdirect} + \gamma_{12}\text{Tstruct} + \gamma_{13}\text{Pracwork} + \mu_{1j}$$
$$\beta_{2j} = \gamma_{20} + \gamma_{21}\text{Stdirect} + \gamma_{22}\text{Tstruct} + \gamma_{23}\text{Pracwork} + \mu_{2j} \qquad \text{Equation 4}$$

In the above model, each of the three science learning scales were centred around the grand mean, so that the intercept, β_{0j}, represents the grand mean science achievement when adjusted for these science learning scales. The β coefficients represent student level slopes which can then be the outcomes for school level effects. In these analyses, the intercept, socioeconomic status of the student and gender were modelled as outcomes.

The results of these analyses are provided in Table 2 for the 12 countries at the 14-year-old level under the section entitled Science Learning Environment Model. The Level-2 predictors for the intercept β_{00} were the average socioeconomic status for the school, γ_{01}, school average for *Student Participation*, γ_{02}, *Teacher Directed Learning*, γ_{03}, and *Practical Work*, γ_{04}. The mean science achievement was the intercept γ_{00}. The latter three Level-2 predictors were also modeled on the student level predictors socioeconomic status of the student, β_{10}, and gender, β_{20}. The error term for the student level model was r_{ij}, while the error term for the school level model was μ_{0j}.

There are a few consistent patterns seen in Table 2 across the 12 countries. Firstly, the significance of the intercepts indicates that these science learning scales do not fully explain the variance in science achievement. This is reiterated by the significance of the intercept slope variance (random effect) for all countries. The average socioeconomic status for students attending a school was positively associated with science achievement across all schools (see γ_{01} in Table 2).

While the teacher directed learning scale was generally significant, it was almost always negative. Exceptions to this effect were Hungary, Italy, Japan, and The Philippines, where the effect was positive (see γ_{03}). Similarly, student directed learning slopes were strong and negative for all countries analysed (see γ_{02}). These findings indicate that the more students managed their own science learning, the lower their science achievement became.

The most significant finding in these analyses was the consistently large and positive effect of the practical work scale on science achievement. It appeared that schools with a larger reported practical work component to their science lessons had improved science achievement (see γ_{04}).

Socioeconomic Equity

The slope for socioeconomic status of the student was estimated with the three science learning scales in order to assess the effect of these scales in explaining differences in performance between students from higher and lower socioeconomic backgrounds.

While student participation in their own science learning management was related to improved achievement for students from higher socioeconomic backgrounds in Australia, this was not a trend across other countries investigated in this study.

The effect of teacher directed learning was noted to be negative for England and Finland, where more teacher involvement was related to improved achievement for students from lower socioeconomic backgrounds. This was reversed for Italy, where teacher involvement appeared to be related to improved performance among students from upper socioeconomic backgrounds.

It was notable that the practical science learning scale was negative for Australia and Italy. That is, students from lower socioeconomic backgrounds were advantaged by increased practical work learning in their science classes.

Gender Equity

When the gender slope was allowed to vary randomly across schools, there was negligible variation in the sex differences in science achievement. The average socioeconomic status of students in the school and the three Science Learning Environment scales contributed little to explaining the variations in sex differences. However, the practical science learning scale appeared to favour males in Finland and females in Hungary. That is, where the science learning environment involved more practical work teaching strategies, male achievement was improved in Finland and female achievement was improved in Hungary.

Summary

This paper attempted to compare the effects of the student reported science learning environment across 12 countries. While these countries are not necessarily comparable in terms of their educational systems, it is worthy to note any consistency in patterns of significant effects on science achievement. In particular, a striking finding was that the increased practical work component in science lessons was associated with improved science achievement by 14-year-old students across all 12 countries examined. Generally, this was true for both male and female students and for students from all socioeconomic backgrounds, with few exceptions. While these findings emerged from analyses involving science learning environment scales with adjustments for student home background and other student characteristics, further research into the science classroom processes are likely to improve the fit of the explanatory model.

The finding that the science achievement outcome varies significantly from school to school has direct implications for research which purports to relate the student learning environment to achievement outcomes. In this research, there was significant variability at the school level and this variability was different for each country. In educational research, the hierarchical linear model is a most effective tool for the analysis of students in schools.

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Correspondence should be directed to:

Dr. Deidra J. Young, Research Fellow, Science and Mathematics Education Centre, Curtin University of Technology, GPO Box U1987, Perth, Western Australia 6001.

Phone: (09) 351 2988
Fax: (09) 351 2503
Email: tyoungdj@cc.curtin.edu.au

Appendix A

Second International Science Study (Australia) Test Instruments for 14 Year Old Students

Test 2M - Core Science Test

1 The Sun is the only body in our solar system that gives off large amounts of light and heat. Why can we see the Moon?

A It is reflecting light from the Sun.

B It is without an atmosphere.

C It is a star.

D It is the biggest object in the solar system.

E It is nearer the Earth than the Sun.

2 About how long would it take a rocket ship to reach the Moon?

A two hours

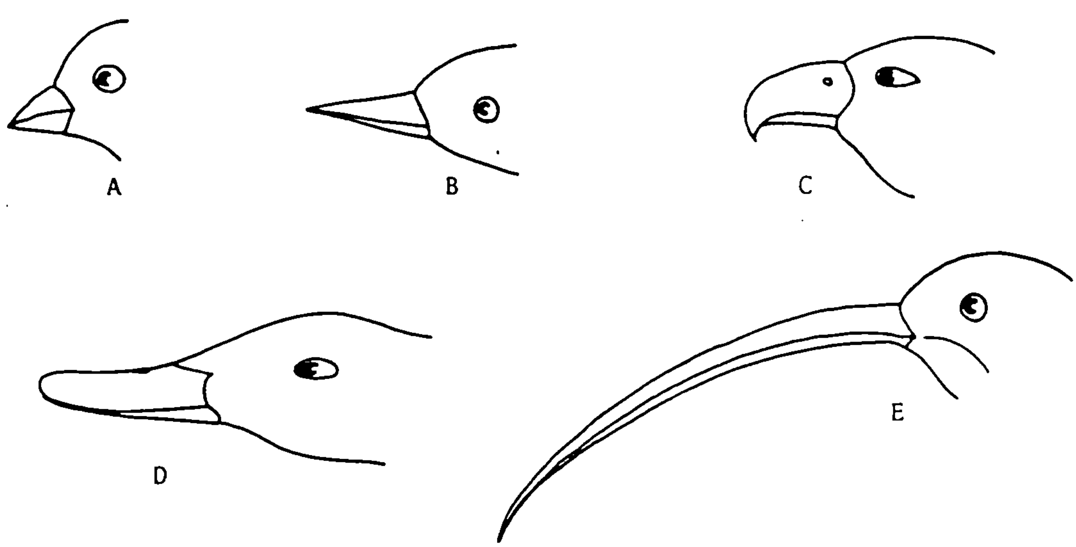
B several hours

C a few days

D a light-year

E several years

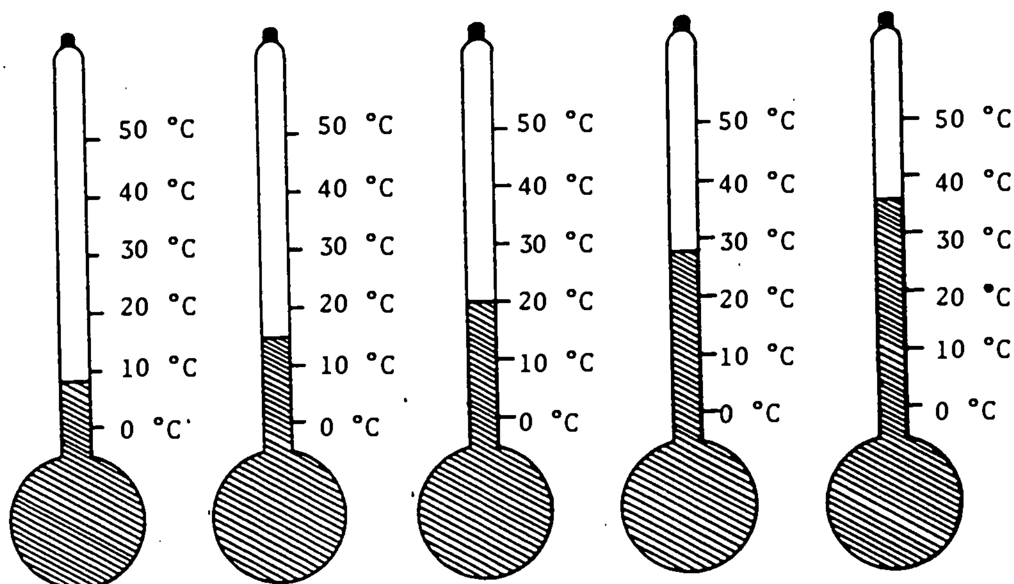
3 A boy sitting under a tree watched a bird getting insects from between the cracks of the bark. Which drawing shows the kind of beak this bird had?



The next two questions refer to the following table which shows some temperature readings made at different times on three days.

	6 a.m.	9 a.m.	12 noon	3 p.m.	6 p.m.
Monday	15 °C	17 °C	20 °C	21 °C	19 °C
Tuesday	15 °C	15 °C	15 °C	10 °C	9 °C
Wednesday	8 °C	10 °C	14 °C	14 °C	13 °C

4 Which of the following shows the temperature at 6 a.m. on Wednesday?



A B C D E

5 On one day a cool wind began to blow. When do you think this happened?

A Monday morning

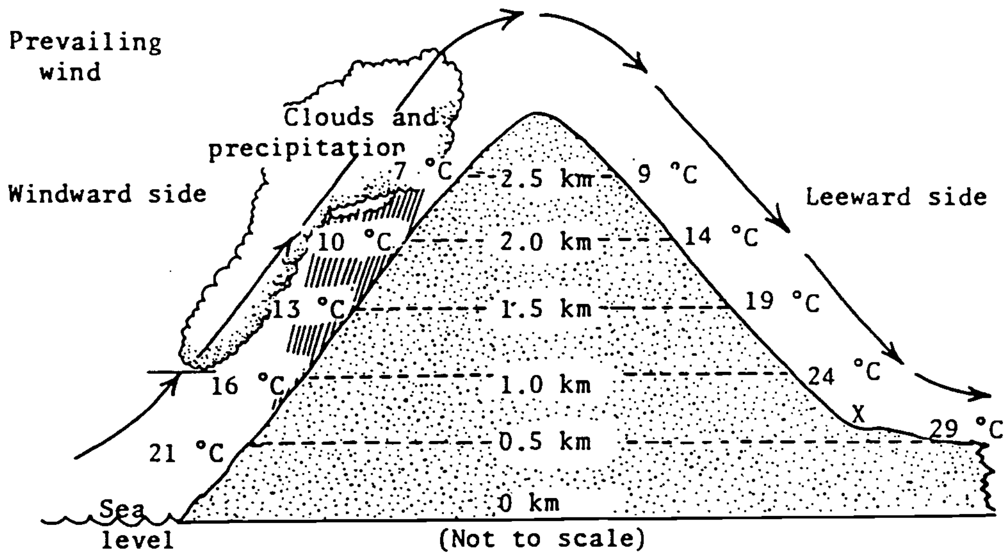
B Monday afternoon

C Tuesday morning

D Tuesday afternoon

E Wednesday afternoon

6 The diagram below shows a mountain. The prevailing wind direction and average air temperatures at different elevations on both sides of the mountain are indicated.



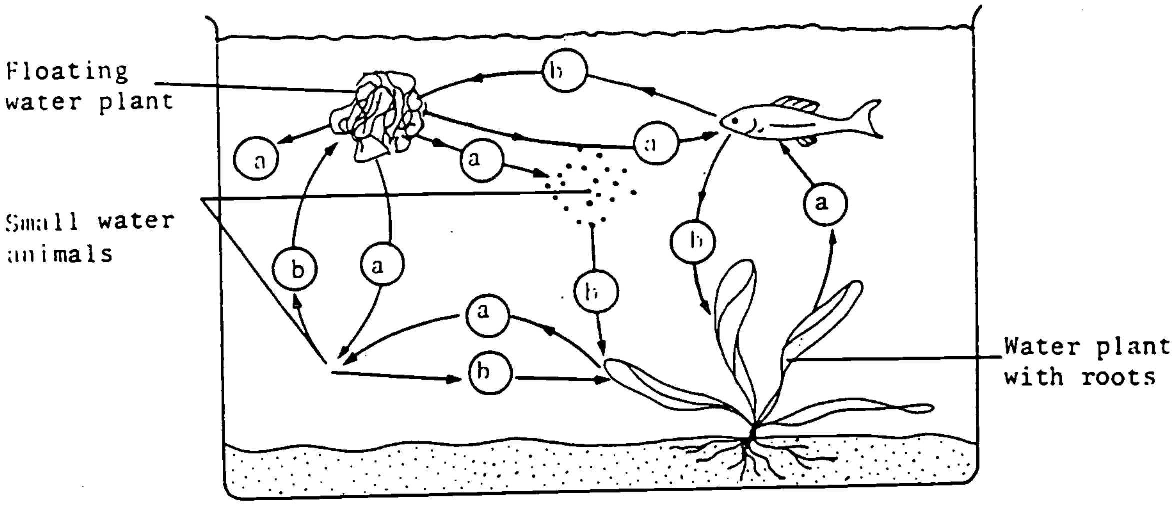
Which feature is probably located at the base of the mountain on the leeward side (location X)?

- A a dry region
- B a jungle
- C a glacier
- D a large lake
- E a rain forest

7 Fossils very similar in shape to marine shellfish which live in oceans today have been found in the rocks of high mountains. What is the most likely explanation of this?

- A The particular marine shellfish can live in the sea or on land.
- B Marine forms once had organs that enabled them to breathe atmospheric air.
- C The rocks in which the fossils were found were formed under the sea.
- D Marine forms, in certain cases, migrate on to the land.
- E Marine forms have evolved from land forms.

8 The diagram below shows an example of interdependence among aquatic organisms. During the day the organisms either use up or give off (a) or (b) as shown by the arrows.



Choose the right answer for (a) and (b) from the alternatives given.

A (a) is oxygen and (b) is carbon dioxide.

B (a) is oxygen and (b) is carbohydrate.

C (a) is nitrogen and (b) is carbon dioxide.

D (a) is carbon dioxide and (b) is oxygen.

E (a) is carbon dioxide and (b) is carbohydrate.

9 A girl found the skull of an animal. She did not know what the animal was but she was sure that it preyed on other animals for its food. What clue led to this conclusion?

A The eye sockets faced sideways.

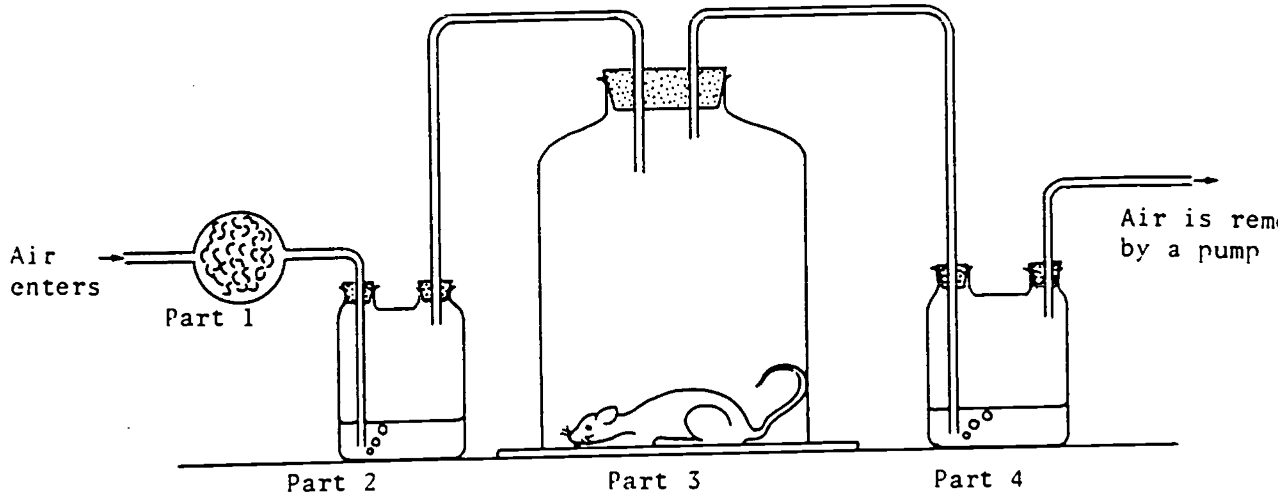
B The skull was much longer than it was wide.

C There was a projecting ridge along the top of the skull.

D Four of the teeth were long and pointed.

E The jaws could move sideways as well as up and down.

10 This question refers to the following diagram of apparatus used to show that an animal gives out carbon dioxide in respiration.



Part 1 contains a substance which removes carbon dioxide from the air passing through it. Parts 2 and 4 both contain a liquid which changes in appearance when carbon dioxide passes through it.

Of the following kinds of containers for the animal which one would give the quickest result?

A a small container

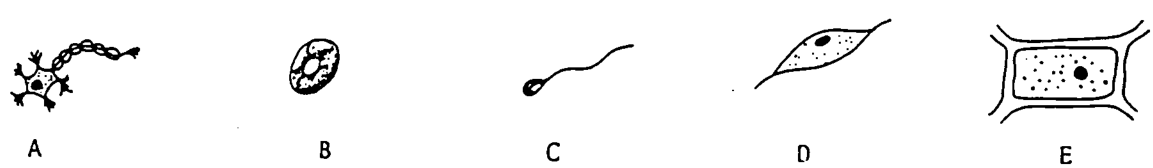
B a large container

C a container in bright light

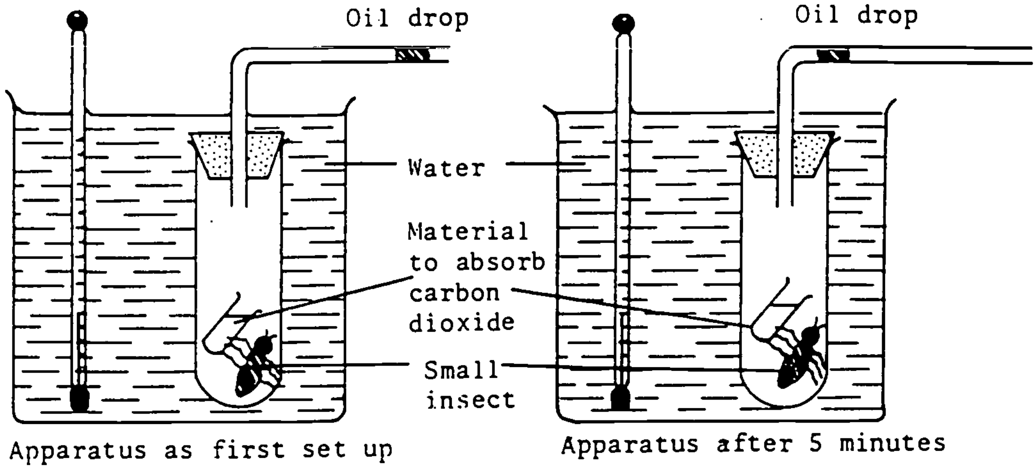
D a container covered with a dark cloth

E a container in which the air is kept moist by means of wet cotton wool

11 Which of the cells shown below would commonly be found in the human nervous system?



12 Animals take in oxygen and give out carbon dioxide. Ordinary air contains very little carbon dioxide.



Which of the following can be measured with the above apparatus?

A The rate of movement of the animal.

B The amount of heat produced by the animal.

C The rate of respiration of the animal.

D The effect of carbon dioxide on the animal.

E The amount of carbon dioxide absorbed by the animal.

13 Which of the following statements is true about seeds?

A Every plant produces seeds.

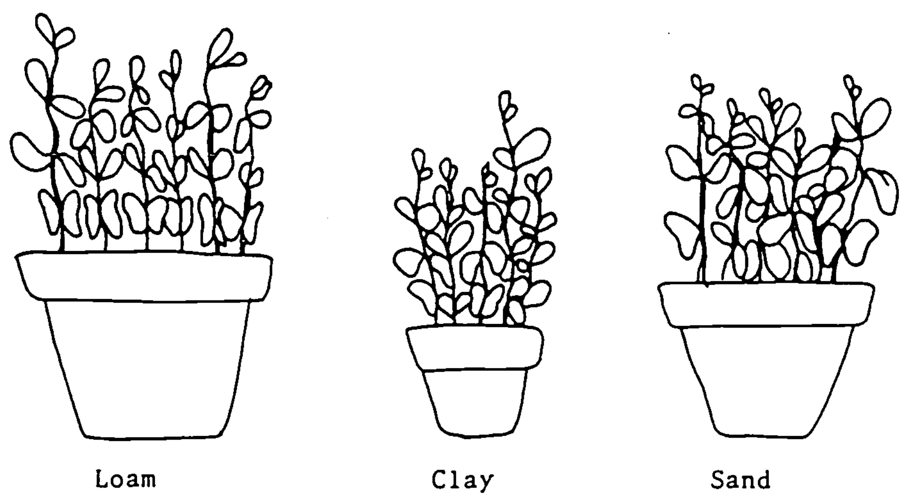
B All fruits contain a large number of seeds.

C All seeds are good to eat.

D Every seed contains a young plant, stored food and a seed coat.

E The food stored in seeds is always in the cotyledon.

14 A girl wanted to learn which of three types of soil (clay, sand and loam) would be best for growing beans. She found three flower pots and filled each with a different type of soil. She then planted the same number of beans in each, as shown in the drawing. She placed them side by side on a window sill and gave each pot the same amount of water.



Why was the experiment <u>not</u> a good one for the purpose?

- A The plants in one pot got more sunlight than the plants in the other pots.
- B The amount of soil in each pot was not the same.
- C One pot should have been placed in the dark.
- D Different amounts of water should have been used.
- E The plants would get too hot on the window sill.

15 Milk kept in a refrigerator does not go sour. Why?

- A The cold changes the water of the milk into ice.
- B The cold separates the cream.
- C The cold slows down the action of bacteria.
- D The cold keeps flies away.
- E The cold causes a skin to form on the surface of the milk.

16 The male insects in a population are treated to prevent sperm production. Would this reduce this insect population?

- A No, because the females would still lay eggs.
- B No, because the insects would still mate.
- C No, because it would not change the offspring mutation rate.
- D Yes, because it would sharply decrease the reproduction rate.
- E Yes, because the males would die.

17 When 2 g (grams) of zinc and 1 g of sulphur are heated together, practically no zinc or sulphur remains after the compound zinc sulphide is formed. What happens if 2 g zinc are heated with 2 g of sulphur?

- A Zinc sulphide containing approximately twice as much sulphur is formed.
- B Approximately 1 g of sulphur will be left over.
- C Approximately 1 g of zinc will be left over.
- D Approximately 1 g of each will be left over.
- E No reaction will occur.

18 Two given elements combine to form a poisonous compound. Which of the following conclusions about the properties of these two elements can be drawn from this information?

- A Both elements are certainly poisonous.
- B At least one element is certainly poisonous.
- C One element is poisonous, the other is not.
- D Neither element is poisonous.
- E Neither element need be poisonous.

19 Paint applied to an iron surface prevents the iron from rusting. Which <u>one</u> of the following provides the best reason?

- A It prevents nitrogen from coming in contact with the iron.
- B It reacts chemically with the iron.
- C It prevents carbon dioxide from coming in contact with the iron.
- D It makes the surface of the iron smoother.
- E It prevents oxygen and moisture from coming in contact with the iron.

20 Which of the following particles are gained, lost or shared during chemical changes?

A electrons furthest from the nucleus of the atom

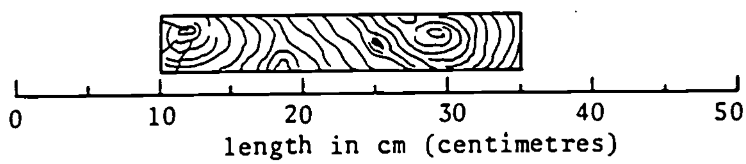
B electrons closest to the nucleus of the atom

C electrons from the nucleus of the atom

D protons from the nucleus of the atom

E neutrons from the nucleus of the atom

21 How long is the block of wood shown in the diagram?



A 10 cm

B 20 cm

C 25 cm

D 30 cm

E 35 cm

22 Mary and Jane each bought the same kind of rubber ball. Mary said, "My ball bounces better than yours." Jane replied, "I'd like to see you prove that." What should Mary do?

A Drop both balls from the same height and notice which bounces higher.

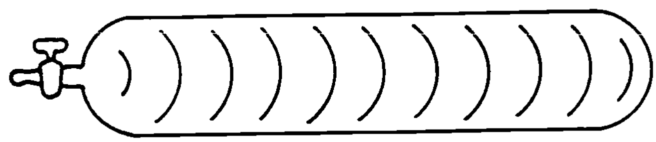
B Throw both balls against a wall and see how far each ball bounces off the wall.

C Drop the two balls from different heights and notice which bounces higher.

D Throw the balls down against the floor and see how high they bounce.

E Feel the balls by hand to find which is the harder.

3 An iron container is weighed after the air in it has been pumped out (evacuated). Then it is filled with hydrogen gas and weighed again.



What is the weight of the container full of hydrogen compared to the weight of the evacuated container?

A less

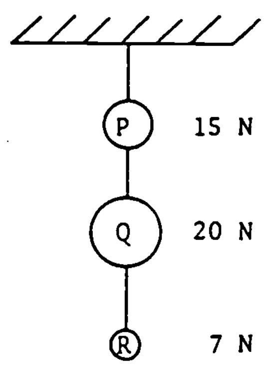
B greater

C the same

D greater or less depending on the volume of the gas in the container

E greater or less depending on the temperature of the gas in the container.

4 The objects P, Q and R of weight 15 N (newtons), 20 N and 7 N, are hung with a light thread as shown in the figure.



What is the tension in the thread between P and Q?

A 42 N

B 35 N

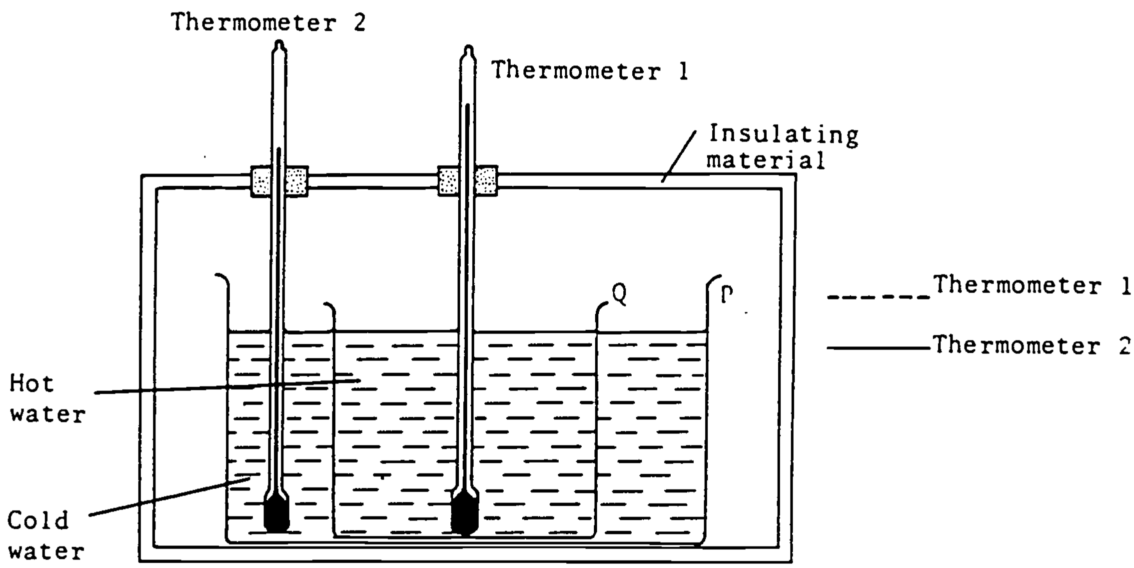
C 27 N

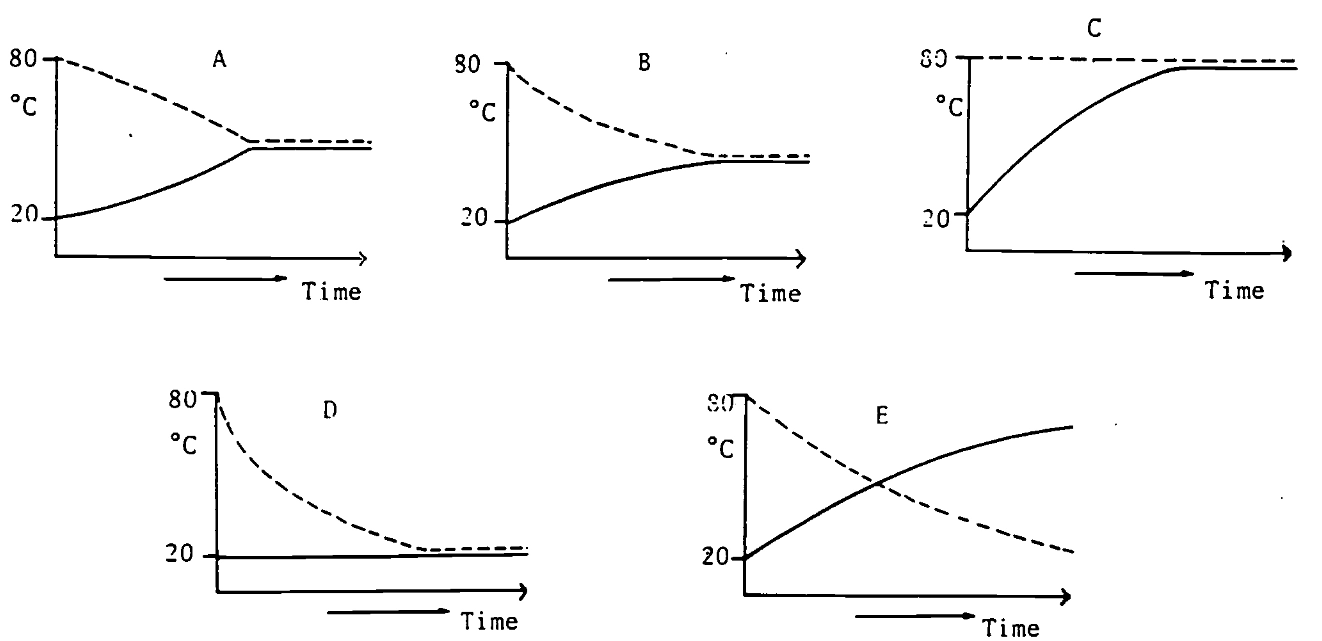
D 15 N

E 7 N

25 Using the apparatus shown in the figure below, 100 g (grams) of water at 20 °C (degrees Celsius) was poured into the outer container P and its temperature read at intervals from thermometer 2. At the same time 100 g of water at 80 °C was poured into the inner container Q and its temperature read at intervals from thermometer 1.

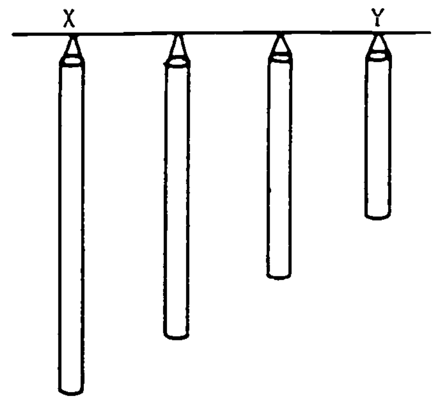
Which of the following graphs best represents the changes in the temperatures of the water in the two containers?





26 A set of chimes was made by cutting four pieces of pipe of different lengths from a long metal pipe and hanging them as shown in the picture below. Which of the pipes gave the <u>lowest</u> note when struck with a hammer?

A Pipe X
B Pipe Y
C All gave the same note.
D You cannot tell without trying.
E It depends on where you hit it.

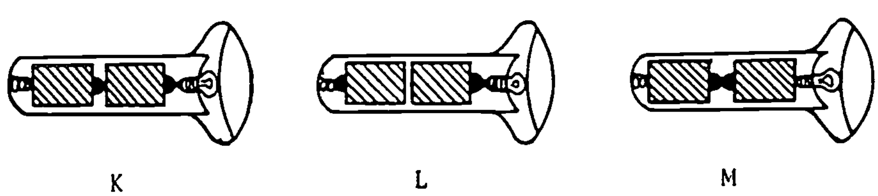


27 A cupful of water and a similar cupful of petrol were placed on a table near a window on a hot sunny day. A few hours later it was observed that both the cups had less liquid in them but that there was less petrol left than water. What does this experiment show?

A All liquids evaporate.
B Petrol gets hotter than water.
C Some liquids evaporate faster than others.
D Liquids will only evaporate in sunshine.
E Water gets hotter than petrol.

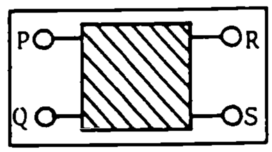
28 A flashlight holds two batteries. In order to make it work, in which of the following ways must we place the batteries?

A as in diagram K
B as in diagram L
C as in diagram M
D either as in diagram L or in diagram M
E none of these would do

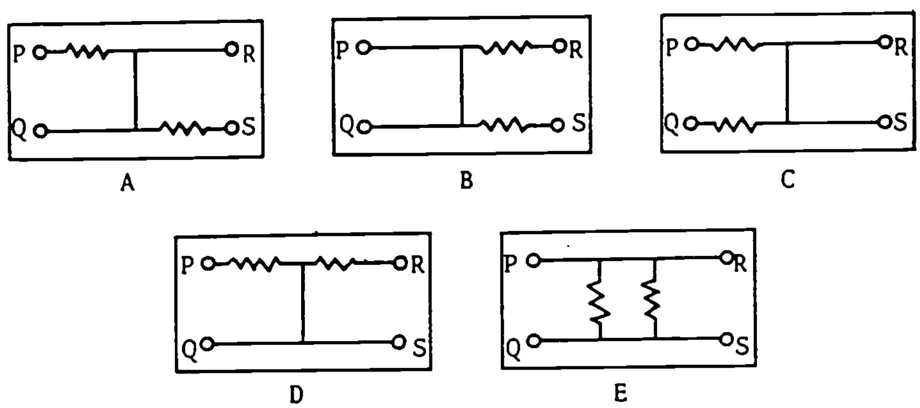


29 The figure shows a box with four terminals: P, Q, R and S. The following observations were made.

1 There is a certain amount of resistance between P and Q.
2 Resistance between P and R is twice that between P and Q.
3 There is not any appreciable resistance between Q and S.

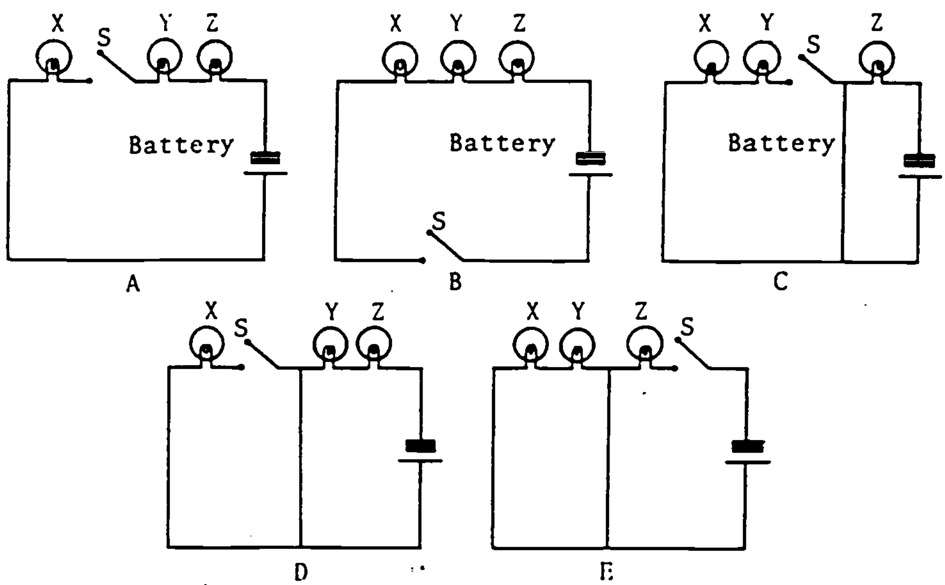


Which of the following circuits is most likely to be within the box? Assume that the resistances shown are equal.



30 X, Y and Z represent three lamps in a circuit, which also includes a battery and a switch S. When the switch is open X fails to light while Y and Z do.

Which of the following circuits is it?



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HLM/2L

By

Anthony Bryk, PhD, University of Chicago
Steven Raudenbush, PhD, Michigan State University
Richard Congdon, Brandeis University

HLM/2L (2-level) is designed to analyze growth and change within individuals; to study responses of persons in organizations such as schools, businesses, community and religious groups; and to conduct meta-analysis of research results.

The program handles two-level hierarchical linear models. Basic HLM theory and the use of the program are described fully in the program manual. The estimation method is empirical Bayes; the EM algorithm augmented by the Aitken accelerator is used in variance-covariance component estimation. The latter has satisfactory computational efficiency and assures that the parameter estimates remain within the parameter space (*i.e.*, no negative variances or correlations greater than 1.0).

Within-unit effects can be either fixed or random. Different between-unit models can be specified for each random effect. Both pairwise and listwise deletion options are provided for handling data in the within-unit model.

The program can be run in either interactive or batch mode. It accepts both ASCII and SYSTAT file input, and residual file output can be read into another statistical program for purposes of examining both the goodness-of-fit model and the tenability of statistical assumptions.

System Requirements and Limitations

The PC version operates under MS-DOS and requires a 640 Kbyte machine with 560 Kbyte of available RAM. A *math coprocessor* and hard disk are required.

The PC program will handle a maximum of 250 units and an unlimited number of cases within units. Up to 20 within-unit variables and 20 between-unit variables may be included in the input stream, but in any one analysis, only 9 within-unit variables and 13 between-unit variables may be included.

The CMS mainframe version will analyze up to 360 units and an unlimited number of cases within-unit. In any one analysis, 15 within-unit variables and 10 between-unit variables may be included. Eight megabytes of virtual memory and the IBM VS FORTRAN runtime library, release 2.3.0 or later, are required.

† Available upon request:

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Author(s): Deidra J. Young

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Signature: D J Young	Position: Research Fellow
Printed Name: Deidra Young	Organization: Curtin University
Address: G.P.O. Box U1987 Perth W.A. 6001 AUSTRALIA	Telephone Number: (619 351 2988
	Date: 22 Feb. 1994