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Conceptualizing Chromatography : Student Misconceptions Revealed by Analysis of Responses to Second International Science Study Process Testing at Grade 9 Level in USA

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INTRODUCTION

This analysis of the responses of 322 students to a practical chromatography task uses data collected during spring 1986 as part of the Second International Science Study [SISS] organized by the International Association for the Evaluation of Educational Achievement [IEA]. The sample, drawn from 39 schools, is a subset of the national sample of U.S. students. The task required students to observe the dispersion of four dots of colored ink on filter paper when it absorbed water, record their observations, and explain the change in a dot of black ink. Students recorded details of their work—observations and their explanations of these—in test booklets. These written records were analyzed to provide a detailed description of student responses, and of concepts invoked by students to explain their observations. To show the types of concepts used in these explanations, a categorization of student responses was produced, in an attempt to group together responses using similar concepts. Literature on explanation in science education, and on student difficulties with chromatography tasks is reviewed. The results of analysis of the student responses are presented and discussed.

EXPLANATION IN SCIENCE EDUCATION

The rôle of explanation in science has received considerable attention from some philosophers of science (e.g. Braithwaite, 1953; Gaukroger, 1978), with some arguing that the purpose of science is explanation. Science students may be expected to respond to questions requiring them to "Explain" or "Describe and explain", to recall explanations previously learned, or to construct their own explanations for phenomena. Despite this, school students' explanations have received little attention, though Solomon (1986) discusses the nature and quality of children's explanations in school science, and Horwood (1988) discusses explanation and description in science education. According to Horwood (1988)—and doubtless the vast majority of those involved with science education would agree—"Science education should contribute to a student's ability to make sense of the world. Describing things and explaining them are critically important activities for achieving that end" (p. 41). While a description may be composed of distinct pieces of information, an explanation should connect these pieces, and link bits of information. Horwood (1988) notes that teachers commonly make inexact use of the terms "describe" and "explain", may use them interchangeably, and combine them— "describe and explain" — for emphasis. Science text materials provide examples where "explain" is used to mean "define a term", and "describe and explain" are used in conjunction for emphasis (Horwood, 1988, p. 44). In both science texts and teachers' tests, "explaining why" may be substituted by "describing how".

> It is a commonplace to see science teachers and pupils use the description of an event or process as equivalent to explaining it. . . . information about a sequence of steps is given with little or no projection onto a causal chain. The putative explanation is given by description of the process (Horwood, 1988, p. 45).

Though work by Dagher and Cossman (1992) identifies the verbal explanatory practices of junior high school science teachers, we know much less about the distinctions which teachers draw —or do not— between description and explanation; what their students learn from this about the activities of describing and explaining; and how the ability to construct explanations may be developed. If in science teaching and texts the terms "describe" and "explain" and the activities of description and explanation are used in variable and confusing ways, this may contribute to students' difficulty in attaining a coherent understanding of the nature of description and explanation in science. Commenting on studies of children's interpretations of natural phenomena, Driver and Easley (1978) say :

> When the focus of science courses is to enable causal explanations to be made on the basis of experience, it is perhaps significant to realise that the very term 'explanation' may mean something different to some

younger adolescent pupils than to their teacher. Even when the responses do reflect 'objective connections' they may, as in the explanation for why clouds move, still be at variance with the 'accepted' view (pp. 69- 70).

Students may lack familiarity with both the content which they are asked to explain in school science and the methods of explanation required of them.

CLASSIFICATORY SCHEMES FOR STUDENT EXPLANATIONS

A number of schemes (Peel, 1971; Sutherland, 1982; Biggs & Collis, 1982) have been developed for classification of the explanations students generate in response to questions. These categorize responses according to the level of complexity exhibited. Sutherland (1982) defined eight levels in a system for classifying explanations generated in response to biology questions, ranging from completely naive, pre-describer (grossly inaccurate or irrelevant), elementary describer (very simple and limited description), describer (some grasp of underlying concepts), extended describer (use of abstract concepts but not as explanations), transitional (occasional flashes of explanation), explainer (full explanations in conceptual rather than perceptual terms), to the highest level — theoretical explainer (explanation in terms of theory and deduction from evidence). Biggs and Collis (1982) Structure of Observed Learning Outcome [SOLO] taxonomy, is intended to reveal qualitative differences in responses to questions, and is structured around four main response categories. Such classificatory schemes indicate that varying levels of response to questions requiring explanation can be characterized qualitatively, and also provide a way of considering student work in a manner which considers both how students construct their answers from information available and the cognitive skills used to do so.

STUDENT DIFFICULTIES WITH CHROMATOGRAPHY TASKS

The surveys conducted by the Assessment of Performance Unit [APU] in England, Wales, and Northern Ireland to assess students' attainments in science provided evidence of the difficulty which both 13 and 15-year-old students had in interpreting their observations in chromatography tasks (Schofield et al., 1988; Archenhold et al., 1988). Most 13-year-olds given an APU chromatography task ['Squink']

> . . . stated their observations rather than trying to explain them. About 10 per cent of pupils did suggest that as the ink rose in the chalkstick it separated into different colours. This observation was not, however, related back to the original ink colour (Schofield et al., 1988, p. 78).

It is further noted that, while the performance of 13-year-old boys on three of five questions requiring explanation of observations included in APU surveys since 1980, was significantly higher on the explanation part, the reverse was true for the 'Squink' task. At age 13, girls exhibited higher performance on all chromatography tasks than did boys. In APU questions involving interpretation of presented information, performance differences between girls and boys at age 13 and age 15, were closely related to question content, with the largest differences in favor of girls at both ages, being for four questions about chromatography (Archenhold et al., 1988).

SAMPLE AND ADMINISTRATION OF SISS TESTS

The written responses of a sample of 322 Grade 9 students drawn from 39 schools in the USA to a practical chromatography task were analyzed to examine the errors they made. This sample was a subsample of the U.S. national sample of Grade 9 students tested in spring 1986 for the Second International Science Study [SISS] organized by the IEA, and the chromatography task was part of the SISS practical testing in science. Sampling and data collection activities in the U.S.A. were carried out by Research Triangle Institute [RTI] as subcontractor for the U.S. Committee of SISS. Two forms of practical test —Form A and Form B— each containing three tasks were used in SISS. At the beginning of a test session each student was allocated to either Form A or Form B, and given the appropriate test booklet which was kept for the entire session. The test booklet contained specific written instructions for the three tasks of of the test Form. Students were expected to attempt all three tasks within the Form given. The chromatography task was one of the test Form B tasks. The U.S. national sample of Grade 9 students to whom Test Form B was administered was 1112 students drawn from 119 schools. The order in which the tasks were performed varied, as students moved from station to station doing the tasks belonging to the test Form which they had been allocated. Only one student worked at a station at any one time, so all tasks were done individually. Ten minutes were allowed to work on each task, with 5 minutes allowed between tasks for the test supervisor to set them up again and monitor the students' movements to the next station. Students were required to indicate their performance of tasks by giving brief written replies to questions asked in their test booklet, and these were collected by the test supervisor at the end of the test session.

DESCRIPTION OF CHROMATOGRAPHY TASK

The chromatography task administered to Grade 9 students in the USA was constructed in the U.S.A. and administered only to U.S. students. Those responsible for its design thought it feasible within the 10 minutes allowed, and suitable as judged by typical curricular demands made of students at that grade level. The task was composed of three subsidiary parts : (1) Observing the movement of four dots of colored ink on filter paper when the filter paper absorbed water ;

(2) Describing the changes in colored dots; and (3) Explaining changes in the black dot. According to the SISS scoring scheme used to grade responses to the task, receipt of full marks for this task, required :

(part 1) Indicating if the coloring from each of the four colored dots moved at the same or differing rates

(part 2) Describing the changes in colored dots

(part 3) Explaining the changes in the black dot. Full credit was given for a response saying that the black ink was composed of a mixture of two colors (or pigments, dyes, or chemicals).

Some students had difficulty manipulating the filter paper and got water on the colored dots. Test administrators had supplies of extra filter paper and were able to cope with the problem (Duffer & Potter, 1986).

METHOD

The original answer books of all students to whom SISS process test Form B was administered in the U.S.A. as part of SISS testing in spring 1986 were obtained from Teachers College, Columbia University, New York. Using Microsoft Works a database was constructed from the responses of 322 of these students. This was then sorted and searched. Files were exported as text files to Filemaker II, and subsequently read as Microsoft Word documents. The study here described is part of a larger study of student responses to SISS practical tests in the U.S.A. (O'Rafferty, 1991/1992). It was hoped to produce a categorization of student responses. However, the schemes previously mentioned, for classifying responses according to the level of complexity exhibited (Peel, 1971; Sutherland, 1982; Biggs & Collis, 1982) did not prove useful for examining student explanations in the chromatography task. This was due both to the brevity of the responses and the fact that when responses with irrelevant or incorrect explanations were grouped together these not only encompassed the vast majority of responses but also grouped together incorrect or inadequate explanations invoking several differing scientific and non-scientific ideas. Hence student explanations were classified by repeatedly sorting pupil responses into groups which were thought to express similar underlying meaning and modifying classificatory categories until it was considered that there were enough subdivisions to accommodate all responses. Prespecified categories were not used. The data used to construct the classificatory system came from reading student responses and then attempting to group responses expressing similar underlying meaning.

LIMITATIONS OF STUDY

There was no provision for testing students who would have been in the sample had they been at school on the day SISS process testing occurred. It is likely that the cost of trying to test such absentees would have been prohibitive, and Doran (private communication, 1991) indicates that this was the simplest option and doing otherwise would have disrupted the timetable for testing established with other schools. There may therefore be a bias in the student sample if, for example, absentees were also generally lower performers on tests of science process skills.

Low student motivation can also threaten assessment, since success or lack of it on the SISS process tests had no specific consequences for the students tested or on their grades for courses. The sample of student behavior would be poor if students made only vague and half-hearted attempts to do the tasks, but there is no mention in the RTI Final Report (Duffer & Potter, 1986) of student indifference to the tests or idleness during them.

Threats to internal validity include errors in data capture and any distortions in analysis of students' responses. Errors in data capture could be due to the time limit, since students had 10 minutes to do the task and do the associated writing, and to students' restricted linguistic and expressive abilities. It should be noted, however, that there was no evidence from students written answers that they were affected by the time limitation. Since there is no possibility of interviewing the students tested by SISS, the analysis must be based solely on their written answers. It is also assumed that their reading and writing skills sufficed to meet the demands of the test —neither impeding understanding of questions nor restricting written responses. Question validity refers to the problems of defining the science content domain appropriate to a national assessment of Grade 9 students' practical science abilities. A description of the conceptual knowledge, science curriculum experiences, and experience of practical science activities of Grade 9 students would be required to decide the issue. Since no such description has been given explicitly by those responsible for the SISS process testing in the U.S., the assumptions underlying the description must be supposed to be embedded in the set of tasks used. The tasks were regarded by those who designed them as a suitable sample of the content domain appropriate to a U.S. national assessment of Grade 9 students' practical abilities in science, and representative of the scientific content and skills which students that age would have learned.

While the concept of validity is commonly associated with the method of assessment, it should not be interpreted solely as inhering in or being absent from an examination, but ought also include reference to the assessor's interpretations of data thus gathered. Cronbach (1971) emphasized that what is validated is an interpretation of data arising from a testing procedure, rather than the test itself. In this study, students' written responses were interpreted. Bell, Brook, and Driver (1985, p. 201) note that to get information about peoples' conceptions "researchers must rely on interpretations of a person's language (either written or oral) their physical actions or both", and say :

> When using either oral or written data, the researcher must construct for herself or himself, a meaning of the language of the student, and hopefully there is considerable overlap between the constructions of the student and those the researcher is imposing on the data (Bell, Brook, & Driver, 1985, p. 202).

Lack of such overlap would constitute a limitation in the present study.

It is not difficult to identify responses involving ideas which do not reflect scientific orthodoxy or which repeat observations, but grouping responses raises the issue of the reliability of this categorization. Categorizing responses, even when categories evolve from reading and re-reading of pupil responses, is a more subjective process than deciding that pupil responses are erroneous. Others working with the same data might not group responses in the same manner—some categories used in the present study might be amalgamated, others further subdivided, and perhaps new ones created. Student responses quoted should enable the reader to decide if the grouping of responses into categories appears reasonable—no claim is made that classificatory categories are absolute.

STUDENT RESPONSES

Two hundred and sixty four of the 322 pupils responded to part (1) of the chromatography task which asked them to observe the rates of movement of colored inks, and to indicate by marking "same" or "different" printed in their test booklet, whether the colored inks moved at the same or differing rates. Two hundred and forty three pupils—or 75%— correctly marked "different". Eighteen (6%) marked "same". Three hundred and sixteen pupils responded to part (2) of the task, which asked for a description of what happened to the color of each dot. Ninety two percent of the pupils tested got full credit for their answers to part (2), and evidently had little difficulty in providing reasonably satisfactory descriptions of what happened to the colored dots. Descriptions of observations generally attended to one or more of changes or lack of change in the color of the dots; the positions of the dots on the piece of paper; and the relative rate at which the dots moved—some commented as if seeing a race between the dots — “first to the top” or “2nd quickest”. While most confined themselves to recording observations, scientific concepts were at times included in their observations, though not necessarily correctly, as in the case that recorded that the yellow and green dots “evaporated upward”.

Students were asked in part (3) to “Give an explanation for what happened to the black dot”, and 93% of them wrote some response, though only 14% produced a scientifically orthodox explanation of what happened to the black dot. A few—counted as respondents—gave answers such as “?” and “I don’t know”. Student responses were categorized by reading and re-reading their responses many times, and trying to group responses thought to express similar underlying meaning or using similar or related concepts. Classificatory categories were modified until it was thought that there were enough subdivisions to accommodate all pupil responses. The data used to construct the system used to categorize pupil responses therefore came from reading the pupil responses themselves. This analysis resulted in student answers being grouped into 18 categories. The following are the final classificatory categories, each illustrated by student explanations representative of those grouped within that category. A complete listing of responses grouped in each category is available elsewhere (O’Rafferty, 1991/1992). The beginning of each distinct student response is marked by “•”. No student responding gave more than one explanation. Responses are quoted unaltered—none has been shortened, and in all cases the original syntax and spelling retained. The number of responses classified within each category is also indicated.

1. *Reference only to rate or movement (including that relative to other colors)*. (14 responses)

•the black dot spread to the top, almost as the same rate as the green, but not as quickly
•It had a faster rate so it reached the top first
•black colors travels faster than other colors
•the colored black area moved upward

2. *Reference only to color at level of description.* (45 responses)
•The black dot turned purple
•the color black had turn into the color purple
•it changed to a few other colors
•it turned all different colors
•The black dot change color very slowly, it turned purple
•it turned purple and blue
•changed colors many times
•all I can tell you that black look like difrent color

3. *Reference to color and to rate or movement including location (descriptive).* (40 responses)
•as the water level rose on the paper the black changed colors and moved upward
•The black dot was the quickest to the top. In the water the black changed colors.
•My black dot turned purple and it reached the top of the paper first
•The black dot was the frist to reach the top and spread out more diffrent colors than the other colors
•it changed colors as it went up to the top
•the black dot moved up and then turned purpleish then it turned blueish
•It turned purple and rised to the top very fast
•it reached the top and turned all kinds of different colors
•turned purple right away, shot straight up, dimmed, turned reddish brown, then went to greens and blues
•the black dot moved to the to the quickist it changed from black to blow then green and purple
•The black dot dispersed from its circle very quickly at the top of the filter paper it turned a bluish color

•When I dunk it in the water, the black dot was the first one giving off color as I turned it and it reached the top of the paper first

•The black was first to reach the top and it had many different pigment shades of different colors

4. *Reference only to position.* (3 responses)

•It rose the highest

5. *Reference to light including mixing of colored lights or spectrum.* (4 responses)

•The black dot ran and when it did the color become lighter turning it the next lighter color on the color spectrum

•When water hit it the light had less control over its color

•Black has all the colors of the color spectrum in it. so it had more colors to go on.

6. *Reference to mixture / reaction of black dot with other colors on the filter paper.* (7 responses)

•The water made the other colors mix in with the black

•the black reacted with the green to make it purple

•it took in all the other colors

•It probably got mixed with another color and changed to purple

7. *Fading or running of color.* (6 responses)

•the color faded into a purple color

•The color (purplish blue) was most sensitive to the water, and since it was the darkest color, ran easily

•it ran

8. *As it got wet it got lighter.* (2 responses)

•When it got wet the Black turned purple. As it got wet the lighter it got.

•as it got wet it turned lighter

9. *There was another color under the black dot*. (8 responses)
•It turned purple because the solution made the black disappear and purple was under it.
•you made a purple dot first then over the purple dot you put a black dot

10. *Reference to strength/concentration of pigment in the black dot / its "darkness"*. (9 responses)
•It probably turned purple because it has a stronger color than the rest. The affect of water only smeared it a little causing it to turn purple and not disappear
•Basically what happened to black dot is that it is a very dark color meanwhile the other ones where very light in color
•it has more color to go to the top because it has more pigment
•The black dot turned purple as soon as the water hit it. While others turned when they reached the top. Maybe because black is such a dark color

11. *Explanations invoking scientific reasons other than the orthodox one*. (30 responses)
•the substance on the black dot was not atracted to th water
•mitosis
•the heavyer ink stayed at the bottom, the light ink whent to the top
•The chemical properties changed when it came in contact with the water solution
•All the colors make up black. The more colors the faster it travels
•The dye reacted to the cup or the pressure from the oxygen
•it has been made of different substances with different densitys. All of the substances were light that is why it rose so quickly
•the color went up to a dry surface because the water pushed it up there
•condences better in water, went faster. soaks it up better
•It was probably the most saluable of all the colors. So it "ran" up the tabs the fastest
•Because the density of the water was higher than that of the color. The coloring rose as the water was absorbed by the paper.
•the color of the black dot will run if it is dipped in iodine
•the black dot may have turned purple because it was made of iodine which in large quantaties appears black, but when diluted, such as by water, changes

to purple •the moisture and strength of the gas caused the color to change and to smear. The different had to do with the gas circulating all the colors into that one small area and giving the black 2 or more different colors.
•I think that the liquid is somthing that makes colors repel except for Red It let the red part of black stay
•The black solution was probably alot thicker than the rest of the solutions
•Paper absorbs water. Because paper is made of wood. So when the water moved through the paper. The dots were absorbed into the water
•the closer to the top it got, the more its color changed because of oxygen in the air
•It reached water faster and probably got to the air in the water faster
•what happened to the black dot was rose very quickly because it absord the water much faster than the others and chemicall makeup was much less dense
•The black dot's particles were lighter so they reached the top first. The black dot turned purple, brown, and blue.
•The die in the black dot mixed with paper turned colors it acted in a way like litmus paper
•The lighter colors rose to the top
•It's color just got lighter and lighter which made it change to the other colors and then begin to darken because of the chemicals

12. *Water / water and paper / paper*. (43 responses)
•The water and the paper made it turn
•when I diped it in the water the black dot started to spread and turn a different color
•when water hits the dot the color changes
•When added to water, the black turned purple
•That when water hits a certain color it may change the color
•The water was absorbed by the specail paper which caused the color to flow upward with the water
•could be the water
•The water made it travel to the top while traveling the color changed
•I guess the water changed it color, from Black to purple
•The black dot changed when coming in contact with the water
•The water & the paper made it turn purple and blue
•the paper is thiner there

•The black dot moved away from the water faster than any other dot

13. *Specific reference to reaction with water / liquid.* (10 responses)
•the color bleeding up towards the top was a reaction to being placed in water
•The black dot turned purple when mixed with the water. A certain chemical reacted differently than with the other colors.
•It had more of a reaction than the green, yellow, or red to the water
•The black dot reacts different in the water. The two chemicals change !

14. *Differential absorption of water.* (4 responses)
•The water affected it the soonest and most radically so it can't absorb water very well.
•it was made with a substance that was very resistant to the liquid
•it must have absorbed the water faster than the other colors

15. *Reference to components / color components of black and/or separation or breakdown of these / the nature of black.* (39 responses)
•The black dot is made up of more than one substance. That is why it had all different colors. They all separated as they went up the filter paper
•black is made up of all differint colors put togeather so when it hit water all the colors seperated
•the black dot ran up and unmixed the colors that were used to make the color black
•The black dot turned to different colors like a spectrum so this means that black color is composed of different colors
•It shows what colors are put in black to make it that color. Like green, blue, purple, red
•colors were mixed together and formed black. When it came in contact with the water all the colors were unleashed.
•the color combined to make up the color separated and this process is known as chromatography
•since black is not one color when it was put in the water it began going through phases of the colors in black
•The black could have been a combination of two colors and therefore as it spread the different colors came out

•Black is not technically a color. It turned different colors because black is many colors merged.
•The black dot when it came in contact with the water began separating into the clors that had formed it including blue, green, purple, brown, and black.
•Possibly was because of the dyes used to make the color black mixing w/ water & paper caused it to change different colors
•Because you can't really create a real black & so the colors in black separated when the water got to them.

16. *Smeared / Thinned.* (11 responses)
•it smeared
•It got wet and smeared
•It smeared because of the absorbancy
•got the dampest and smeared up to the top
•when the water hit it It ran like a wet magic marker. It smeared
•It smered but it had no real reaction nothing such as a chemical change more of a small change
•the water thinned it so it smeared easier
•It got thinned out and the colors broke down

17. *I don't know or similar.* (11 responses)
•I do not know what happened to the black dot.
•I don't really know. I dont know what kind of water or [ul] paper it was and I don't know what kind of coloring it was

18. *Incomprehensible/ incoherent / incomplete / illegible.* (9 responses)
•the color mix with the Iocwed to change its color

Student responses to the chromatography task indicate that while 92% of students tested gave a satisfactory description of what happened to the colored dots, giving a scientifically orthodox explanation of what happened to the black dot was much less common. A very wide range of "explanations" were given, some of which merely reiterated previously recorded observations, referring to the rate of movement of the dots, to the color of the black dot at the level of description, or to the final position of the black dot on the paper. The multitude of responses in which observations were reiterated as explanations, suggest that many did not or could not distinguish between observations and explanations. Few causal explanations offered were scientifically orthodox. Many produced scientific-sounding explanations, involving ideas that the black dot mixed or reacted with other colors on the filter paper; that its color faded or ran; that there was another color under the black dot; that the change was due to reaction with the water or with the water and paper; that the concentration of pigment in the black dot was implicated; or that differential absorption of water by the dots was. Some attributed the change to the dot getting wet and smearing; or invoked ideas about light including the mixing of colored lights and the spectrum. A wide variety of scientific concepts were invoked in students' attempts to give an explanation. These ranged from the entirely irrelevant "mitosis", through statements using ideas of weight and density ["the heavyer ink stayed at the bottom, the light ink whent to the top"]; a reaction ["The dye reacted to the cup or the pressure from the oxygen"]; relative solubility ["It was probably the most saluable of all the colors. So it "ran" up the tabs the fastest"]; relative 'thickness' of the ink solutions ["The black solution was probably alot thicker than the rest of the solutions"]; and mentioning oxygen ["the closer to the top it got, the more its color changed because of oxygen in the air"].

The other two tasks of SISS test Form B as administered in the USA were a task on density which involved finding the density of a lead sinker, and a task on testing for sugar and starch. In the latter, students were provided with iodine solution and sugar testing tape in order to test for the presence of sugar and starch in three solutions. There may have been some inappropriate transfer from these other tasks, with the former encouraging some to think about density and the latter leading to the responses: "the color of the black dot will run if it is dipped in iodine"; and "the black dot may have turned purple because it was made of iodine which in large quantaties appears black, but when diluted, such as by water, changes to purple".

COMPARISON OF PRESENT AND U.S. NATIONAL SAMPLES

A comparison of the scores obtained on the chromatography task by the present sample of 322 students and those of the U.S. national sample of

Grade 9 students indicates that the present sample differed little in performance on the tasks from the U.S. national sample of which it was a subset. Seventy four percent of the national sample (Kanis, Doran, & Jacobson, 1990) and 75% of the present sample were given credit for part (1). Applying the SISS scoring scheme used in the U.S.A., 296 students (92%) of the present sample were given full credit for recording observation in part (2), while 95% of the national sample were given full credit for the same item. SISS scoring awarded 14% of the present sample credit for their explanations of the change in the black dot, which it gave to 12% of the U.S. national sample.

RATINGS OF OPPORTUNITY TO LEARN

Teachers of students tested in the SISS were asked to evaluate the opportunity which those students had to learn the concepts and/or skills tested in each of the practical tasks. Opportunity to Learn [OTL] data is based on reports of teachers of all of the students to whom SISS practical tests were administered, as it was not possible to separate the reports of teachers of the present sample. According to the OTL ratings 40% of the teachers thought their students had learned the skills and/or content needed for the chromatography task either in the science course of an earlier year or the present year's course of study, with 44% responding that it would be covered in a future science course; 15% that they did not know if it was included; and 6% that it was not part of the science program in their school (Kanis, 1988, p. 216). Since these report the opinions of teachers of all Grade 9 students tested, caution must be used in relating them to the performance of the present sample of students. Neither is it clear what these teacher responses mean. In the case of the chromatography task teachers may believe that the majority of their students have had the opportunity to learn about chromatography if they ever made a chromatogram or saw one made, or even if chromatography was mentioned in class.

DISCUSSION

The results of the present study are in broad agreement with those of APU studies in England, Wales, and Northern Ireland which found that 13 and 15-year-old students had difficulty interpreting their observations in chromatography tasks. Schofield et al. (1988) suggested that the difficulty of the underlying concept which had to be recalled in order to explain observations was one factor influencing student performance in an APU chromatography task. If, however, students have not previously seen a chromatogram or done practical work involving use of chromatography, expecting them to produce a scientifically orthodox explanation of observations may be to ask the well nigh impossible, in addition to carrying the suggestion that scientific theory is related in a deductive and unique way to observations.

In view of the APU finding that girls exhibited higher performance on all chromatography tasks than boys, it had been hoped to investigate the relative performances of girls and boys tested by SISS. However it transpired that the ID numbers on students' answer books were recoded when information, including gender, was put on SISS data tapes, and that there was no way to relate the ID numbers on the answer books to those on the SISS data tapes from which it had been intended to extract the information on student gender.

Results suggest that students may have difficulty distinguishing between descriptions and explanations, and in constructing scientifically acceptable explanations of phenomena. Students' understanding of what constitutes an explanation may differ from that of their teachers, and they may lack familiarity with the content or observations they are expected to explain and with scientific modes of explanation. The widely-held if ill-founded view that school science studies should seek to reflect the nature of science suggests students should imitate the behavior of scientists. Adherence to such a position seems likely to influence the rôles attributed to student observations and explanation of those observations in school science, but pays inadequate attention to the difference between the elaborated prior knowledge of scientists and that of students. Inference from observation may be high for a scientist equipped with substantial background information accumulated over years of work on a specific topic, but this is not likely to be the case for a student observing the same phenomenon—possibly for the first time. Study of cognition suggests that experts and novices do not differ solely in the amount of information each has, but also in the extent to which that information in organized into a meaningful structure. When students are required to explain their observations of a scientific phenomenon with which they are unfamiliar, they are confronted by a task requiring that they behave "like scientists". Both the inadequacy of their background information and lack of familiarity with the nature of the explanation expected reduce the likelihood of their being able to produce a scientifically orthodox explanation. As Hodson (1988) comments :

> The suggestion that initial, unprejudiced observations lead infallibly to conceptual explanations is both philosophically and psychologically absurd. For children to "discover" anything at all they need a prior conceptual framework (1988, p. 23).

The wide range of scientific concepts invoked by students to explain their observations suggest that, for many, their existing conceptual framework was inadequate to allow them "discover" the orthodox explanation. Hanson (1958), articulating the view that theory determines observation, said that what we see is determined by what we know, and distinguished between "seeing as" and "seeing that". In the former of these, observations are made without prior knowledge, and focus on literal description of patterns. Observations made as "seeing that" are made with prior knowledge of the subject of the observation. Within such a framework, most students in the present study may have been able to describe what they saw—functioning as "seeing as" observers, though lacking adequate prior knowledge to be "seeing that" observers.

The description of students' explanations provided in this study may be of use in informing teachers, student-teachers, and those with responsibilities for teacher preparation and the design of practical science tests about students' difficulties. Additionally they suggest the utility of further studies of students' explanations, and of their ability or inability to distinguish between descriptions and explanations. The adequacy or otherwise of the distinctions drawn between descriptions and explanations by science teachers and texts and the influence of these on students' explanations merits study.

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