# Hong Kong primary pupils' cognitive understanding and reasoning in conducting science investigation: A pilot study on the topic of "Keeping Warm"

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## Abstract

With the increase in prominence of the investigative approach in Hong Kong science curricula from the primary to the senior secondary level, there is urgency for local science educators including primary school teachers to gain a better understanding of pupils' existing cognitive understanding and reasoning ability for performing science investigation. This is to allow teachers to see where pupils stand in relation to investigation so as to seek a better way to nurture the investigative approach. This paper reports the preliminary findings of a pilot project aiming to reveal the existing cognitive understandings of primary pupils which may facilitate or hinder them to conduct scientific investigation. Using an investigation task on heat conduction as a probe, the study reveals that Primary 4 and 5 pupils, though limited in their understanding and ability to design a reliable and valid investigation, were quite ready to maneuver through the process and were able to evaluate their design by reflecting on their experiences. It was also found that the Primary 5 pupils exhibited a better understanding and reasoning ability than their Primary 4 counterparts in these aspects.

# Introduction

Recent curriculum reforms in science in Hong Kong shows a steady trend of moving from stage-managed heurism to a more genuine investigative approach which focuses on the solving of scientific problems. The trend was first seen in the Teacher Assessment Scheme in Advanced Level Biology and then in the Junior Secondary Science curriculum implemented in 2000 (CDC 1998). The new primary General Studies curriculum also strongly recommends the adoption of the investigative approach in teaching science-related topics (CDC 2002a). The Curriculum Development Council has also formulated a set of objectives under the category of "Scientific Investigation" at different key stages across the Science Key Learning Area from Primary 1 to Secondary 5 in a progressive manner (CDC 2002b, p.20). The main target is "to develop science process skills and understanding of the nature of science". This implies that science investigation is not only regarded as pedagogy for teaching and learning but also treated as an important aspect of the nature of science which should form part of pupils' understanding of the discipline.

In the light of this fervour to place scientific investigation in a more central position of the school curriculum, we feel compelled to ask two questions:

1. What are the levels of cognitive understanding or ability reached by pupils at different grade levels which enable them to conduct science investigation?
2. How does this inform curriculum planners or teachers in setting appropriate targets and in designing a more effective curriculum for these pupils to enhance their ability to use the investigative approach?

This paper is a report of the preliminary findings obtained from a project entitled "Hong Kong Primary Pupils' Ideas in Science Investigation". The aim of the project is to find out how Primary 4 and 5 pupils go about investigations so as to reflect on their understanding and reasoning behind the process. As data analysis still continues, this paper will report only the preliminary findings of part of the study. Before presenting these findings and discussing the insights drawn, we consider it useful to revisit the characteristics of scientific investigation in order to put our discussion in context. We then review briefly some of the theories of cognitive development, and research findings which further our understanding of the progressive development of children's reasoning in science investigation.

## Scientific investigations and their demand on cognitive understanding and reasoning

Investigations can be characterized as problem-solving activities involving the use of science processes including formulating hypotheses, making predictions, designing experiments, observing, measuring, analyzing data and evaluating methods (Watson and Wood-Robinson 1998). Shulman and Keislar (1966, cited in Etheredge and Rudnitsky, 2003, p 10) described scientific inquiry in form of a four-step model which involves problem sensing, problem formulation, searching and information gathering and problem resolving. The Assessment of Performance Unit (APU) of the U.K. adopted a more refined model which sees investigation as a number of systematic progressive steps including: problem identification, reformulation of testable question, planning the investigation, conducting the investigation, recording data, interpreting data, and drawing conclusions, evaluation of methods and results which leads to further formulation of problems, or change in design or technique before students come up with a solution to the problem (Gott and Murphy 1987).

Millar, et al (1994) devised another model in their Procedural and Conceptual Knowledge in Science Project (PACKS) on the basis of the APU model. The PACKS model was formulated from results of observation of groups of 9 to 14 years old students performing investigation. It depicts investigation as a five-stage process which resembles the APU model to a certain extent. The five stages are: given task, task-as-interpreted, a set of observations or measurements, a stated conclusion, and evaluative comments on the conclusion(s) (Millar 1994, p.222) The model further describes the kinds of knowledge students are required to draw on to tackle the problem-solving task. Such knowledge consists of declarative knowledge of science concepts and procedural knowledge of scientific investigating. To explain these two types of knowledge in terms of the five-stage model, the declarative knowledge is students' understanding of the science knowledge relevant to the task so that students could formulate suitable hypotheses or know what to observe. Procedural understanding refers to three aspects essential to the problem-solving process. The first aspect is the understanding of the nature and purpose of the task, that is, whether or how far students can identify with the purpose of the task as a scientific investigation carrying with it the notions of fair test, etc. The second aspect is the ability to carry out relevant manipulative skills so that measurements could be taken and data presented. The third part is seen to be crucial. It is the understanding of criteria for evaluating the quality of empirical evidence, also known as concepts of evidence, which informs different stages ranging from designing experiments, controlling variables, choosing sufficient values for measurement, judging the reliability of data, drawing appropriate conclusions, to evaluating methods and results of the investigation. The concepts of evidence were further elaborated by Gott, et al (2003) to include detailed steps or criteria such as sample size and method of data presentation to ensure reliability and validity of the design. They argued that some students would pick up these ideas in the course of studying science through a traditional approach, but many would not do so unless they were specifically taught. It is this kind of understanding that we believe are important to inform curriculum planners and teachers in designing curriculum and instructional strategies that promote inquiry.

## Children's cognitive development in relation to their ability to investigate

Before reviewing previous researches on how this kind of cognitive understanding progresses across different grades, it is useful to revisit theories of cognitive development relevant to science learning as a background for discussing how pupils' understanding may progress. Our understanding of children's cognitive development is contributed by researchers like Piaget, Bruner, Gagne, Ausubel, and more recently by the theory of constructivism. Piaget's work on genetic epistemology theorizes that cognitive development of humans takes place through a series of continuous and progressive stages, namely preoperational, concrete operational and formal operational stages (Inhelder and Piaget 1958). As the child grows, his or her mental structure develops as a result of interactions with the environment by the processes of assimilation and accommodation. These stages are sequential and age-related and do not seem to vary much across individuals.

Piaget's work has considerable impact on the design of science curriculum whose nature fits closely with his conjectures. His stage theory implies that the curriculum should be matched to the stages of cognitive development of children so that children could benefit more from the curriculum. Lawton (1978) maintained that Piaget's influence was more on discouraging teachers to include something in the curriculum at too early a stage in children's development rather than on encouraging them to introduce curriculum contents at the most appropriate stage. Since the cognitive structure characteristic of a stage will become integrated into that of the following stage, if the child is denied the experiences required for the development of a particular stage, the development of the stage that follows may be hampered. Some earlier curriculum projects, for example, the Science 5/13 of the U.K. and Australian Science Education Project were structured on the basis of Piagetian stages. A more recent attempt to apply Piagetian stages in the curriculum is the Cognitive Acceleration through Science Education Project (CASE), which aims to accelerate pupils' cognitive development (Adey 1998). It claims to achieve considerable successes in elevating pupils' levels of attainment by designing instructions ahead of the cognitive development of children (Adey, Shayer et al. 2001).

In addition to Piagetian theory, Bruner's ideas of cognitive development also recognize the progressive development of children through a sequence of stages. He believed that a child could learn if the material presented and the process through which it was presented corresponds to his stage of development (Bruner 1960). He advocated that the curriculum of a subject should be organized in such a way that pupils learned the basic principles and fundamental structures before specific topics were taught. He argued that children could grasp science at a very early stage and curricula should be designed to teach pupils in an appropriate way and built on children's experiences in increasingly abstract ways as education progresses.

Deviating from genetic epistemology, the theories of Gagne and Ausubel focus mainly on the process of learning by children. Gagne argued that what a person could learn depended on what he or she had already known. He explained that many topics learned in school were sets of concepts organized in hierarchies. The learning of the concepts at the lower levels of the hierarchies is pre-requisite to the learning of more complex ideas at higher levels (Gagne 1985). In other words, pupils have to learn simple ideas before they can make sense of more complicated ones. Ausubel shared a rather similar line of thought as Gagne. He proposed that learning was possible only when students could make sense of new ideas with the structure of thought established by previous learning. Whether learning is meaningful depends on how well these new ideas fit into the existing structure (Ausubel 1968). His arguments imply that learning is basically a constructive activity and a gradual process in which new ideas are built on previous structures.

Another challenge to the stage theory of cognitive development comes from the social constructivists. One major criticism against Piagetian view is that the context in which development of knowledge takes place is ignored. The constructivists see the social context as a very important factor influencing learning since a decontextualized learning environment rarely exists (O'Loughlin 1992). The social constructivist view of learning in the context of science implies that there is a much more important role to play by social interactions in the development of knowledge apart from genetic maturation.

Two views of cognitive development appear to exist: one based mainly on genetic maturation as a result of the individual interacting with the world, which is chiefly determined by age; and the other premised mainly on the learning experiences presented to the learner taking into account all the social and contextual variables. It seems highly likely that both age-related maturation and enculturation are important in influencing cognitive development in a child. No matter which view one tends to adopt, it seems essential for the teacher to have a good understanding of pupils' existing structure in order to design a curriculum that could further enhance their ability to investigate.

## Research on pupils' cognitive understanding and reasoning in scientific investigation

Research data have accumulated on the progression of cognitive understanding and reasoning of children for solving problems in scientific investigation. Findings of the surveys conducted by the APU of the U.K. show that the performance of students aged 11, 13 and 15 tended to vary across tasks set in different contexts. Also, when children's performance in ages 12 and 14 was compared, it was found that many pupils did not make progress but rather going backwards (Strang et al 1991, cited in Kanari 2000, p.65). The National Curriculum Council project conducted after the APU survey found that there was overall progression in pupils' performance with age (from Year 7 to 9), but the change was small compared with the effect of different concept areas (Gott and Duggan 1995 p.58).

In studying pupils' scientific reasoning between 9 to 14 years of age (Year 4, 7 and 9), Millar et al (1994) identified four forms of understandings of the purpose of investigation by pupils. They were labeled as engagement, modeling, engineering and scientific frames. The engagement frame is characterized by engagement with the apparatus without obvious purpose. The modelling frame is employed to produce a desired appearance, an effect, or a phenomenon. The engineering frame refers to the optimization of the desired effect by seeking a combination of factors through trial and error. The scientific frame is the use of a scientific approach in clarifying the relationships between variables. The researchers found that in an investigation on heat transfer, many students chose frames other than the scientific frame. The shift in frame was not very obvious. In the Year 9 Group, fewer than half of the pupil groups used the scientific frame. In another task that deals with forces and motion, which requires the manipulation of two continuous variables, many Year 9 students failed to understand the continuous nature of the variables. Many of them used bar charts to represent data of continuous nature. Pupils of all three year groups did not have adequate understanding of the significance of quantitative data in relation to objective evidence.

Kanari (2000) reported a study on children aged 9, 11 and 13 of mixed abilities in six schools in Northern England. The pupils were presented with an investigation task involving a causal independent variable and a non-causal independent variable. The study focuses on four areas of pupils' performance including choice of initial hypotheses, investigative strategies, conclusions and reasoning from data to conclusion. The findings show that no significant age effect was found in pupils' choice of initial hypotheses, in the likelihood of children reaching the conclusion, and in children's understanding of error and variability of measurement. Nevertheless, older children were more able to spot and take advantage of the hint given about the need of a 'fair test'.

From a contructivist's perspective, the development of scientific reasoning in children is likely to be determined by their previous experiences including those obtained inside and outside school. These experiences are likely to vary across different countries or areas where science curricula are different. This implies that Hong Kong pupils may have a unique profile compared with their counterparts in, say, the U.K. where there is a long tradition of inquiry-oriented practical work. With the implementation of the new curriculum in primary schools which emphasizes the investigative approach, it is worthwhile and important at this particular juncture to study pupils' reasoning underpinning scientific inquiry and how it varies with age. Such findings could provide essential background data of primary pupils in different grades in order to inform the design of appropriate curricular strategies for enhancing pupils' understanding and performance in scientific investigation.

## Purposes of the study

This study was intended to be a pilot research in response to the two questions raised in the beginning section and the literature review. To put them in more specific terms, they are

1. to gauge the current cognitive understanding and reasoning ability of primary pupils in Grade 4 and 5 for tackling scientific investigation, with particular reference to the experimental design, the way that the plan was implemented, and the evaluation of the design and the results; and
2. to identify whether there are any differences in this kind of understanding and ability between Grade 4 and 5 pupils.

There seems to be a general presumption in Hong Kong that pupils will progress evenly. This study will examine whether this is true in the context of scientific investigation and in what ways pupils in the two grades might differ.

## The sample

The sample of the whole study consisted of two Primary 4 classes and three Primary 5 classes from a total of three local primary schools. All the three schools (A, B, and C) were regarded as typical in that they were situated in public housing estates and with pupils of mixed abilities. The two Primary 4 classes were from Schools A and B and the three Primary 5 classes were from Schools A, B and C respectively. The age range of the Primary 4 pupils was from 9 to 10, while the age range of Primary 5 pupils was from 10 to 11. Only Primary 4 and 5 pupils were selected as the subject because they were considered to be more disciplined and could work more independently than their lower grade counterparts. Primary 6 pupils were not involved because of their commitment in high-stake assessments for promotion to the secondary level. Each of the classes involved was divided into seven to eight groups, with four to six pupils in each group. The original groupings of the class were retained to minimize disturbances to the pupils.

## Methodology

This study adopted a qualitative approach. Reference was drawn from other research studies reviewed in this article but it is not our intention to replicate any one of them. Two sets of investigation tasks, one on heat flow ("Keeping Warm" and "Keeping Cold"), and the other on falling motion ("Seed Model" and "The Fastest Seed") were designed to probe pupils' understanding and reasoning in scientific investigations. The two tasks within each set are inter-related and progressive in nature. This is to allow exploration of pupils' nature of reasoning in the same context but at a greater depth. The English translation of the activity sheet "Keeping Warm" is provided in Figure 1.

Activity One: Which kind of cups is the best to keep water warm?

1. Select three cups for testing their effect in keeping water warm. (Please circle your answer.)

a. paper cup    b. soft plastic cup    c. hard plastic cup    d. foam rubber cup
e. steel cup    f. porcelain cup

2. Which of the three cups do you predict is the best one to keep water warm? Why?
The best cup to keep water warm is : ________________________________

I believe the reason is ______________________________________________

3. Design an experiment to find out the best and the worst cup to keep water warm. Write or draw your methods. The following materials are provided for you:-

Hot water, different cups, 3 thermometers, a measuring cup

My design

My group's design

4. Carry out the experiment and record your results.

5. From your results, which is the best cup to keep water warm?

______________________________________________

6. Explain why this cup is better than the other ones in keeping water warm?

______________________________________________

7. Do you think your results are accurate or not? Why?

______________________________________________

8. In what ways could you improve your experiment to make the results more accurate?

______________________________________________

Fig. 1: *Activity sheet for the "Keeping Warm" Task (Translation from Chinese)*

Because of time and manpower constraints, each class was asked to perform only one set of tasks. One Primary 4 and two Primary 5 groups worked on the tasks on heat flow, while another Primary 4 and Primary 5 groups were assigned to the tasks on falling motion. Each pupil was distributed a worksheet for each task which contains a problem reflecting the purpose of the investigation, and a series of questions to prompt him/her to resolve the problem. The questions were considered essential as a guide because the pupils had not received training in tackling scientific problems through self-directed investigation. However, no hints were provided to students with respect to the steps taken apart from the equipment and materials provided. Hence the tasks were relatively open. The worksheets also facilitated pupils to record their hypotheses or predictions, experimental design, results, conclusion, and results of evaluation.

A rather atypical method adopted was to engage final year teacher trainees to serve the dual role of observer and group facilitator. Each student-teacher was assigned to one or two groups. The observers observed the performance of their groups and took field notes about what pupils said and did throughout the process. In order to allow more freedom for the observers to record whatever they considered relevant, they were not provided with any pre-designed code. As facilitators, they helped to ensure that their groups progressed through the task within the designated period of time, normally one and a half hour for each set of tasks. Another role of the facilitator was to engage pupils on task all the time, and to clarify the meaning of the questions on the worksheets whenever and wherever necessary. He or she also posed questions to pupils to clarify their procedures and explore their thinking behind while avoiding giving clues. The responses of pupils were also recorded in the facilitator's field notes. Training was provided to the observers/facilitators beforehand so that they fully understood their roles. This method was proved to be of great value in obtaining more substantive data given the limited ability of primary pupils in comprehending questions and in expressing their plans or answers in written form. The facilitator also helped to ensure that pupils filled out their worksheets. As reported by Lee (2003), even for junior secondary pupils, their ability to write out investigative plans did not reflect their actual ability in planning. Moreover, it is a common experience of teachers that many academically less inclined pupils tend to avoid written work, especially when open answers are required.

The observer's field notes and student worksheets were scrutinized carefully and categorized according to their similarities to generate response categories with respect to the three themes: the experimental design, the way that the plan was implemented, and the evaluation of the design and the results, as mentioned in the purposes of the study.

## Results

As data analysis of the other tasks is still going on while writing this paper, we presented only the results of the "Keeping Warm" task in this preliminary report. The data were obtained from one Primary 4 class of School A, and two Primary 5 classes, one of School B and the other of School C. The data was obtained from 22 groups, totally 99 pupils. All pupils did not have experience in carrying out scientific investigations before the study. However, they should all have acquired some basic concepts of heat flow and heat loss when they studied General Studies in Primary 2. The data obtained through observation, facilitator-pupils exchanges, and pupil worksheets were categorized and presented in three headings: planning, implementation and evaluation. Tables 1 and 2 show different categories of pupils' performance by grade levels in respect of planning and implementation of the task. Since pupils planned the investigation and collected data in groups, the data were reported in terms of number of pupil groups. Table 3 shows the pupils' evaluation of experimental design and results. As this part was performed by individuals, the data were reported in terms of number of students. The categories in the three tables were set up to reflect the characteristics and peculiarities of pupils' reasoning with regard to the three aspects of investigation.

| Pupils' performance during planning | Number of pupil groups | |
|---|---|---|
| | Primary 4 (N= 8 ) | Primary 5 (N= 14 ) |
| *Control of variables* | | |
| 1. Used the same volume of water for all cups | 4 | 10 |
| 2. Put the thermometers into the three cups at the same time for measuring the initial temperature | | 1 |
| 3. Added water to the three cups at the same time | 1 | |
| 4. Checked that the temperature of the three thermometers was the same before putting | | 2 |

| | | |
|---|---|---|
| them in the water. | | |
| | | |
| *Measurement of dependent variables* | | |
| 1. Measured the initial temperature | 1 | 2 |
| 2. Took one temperature reading after an unspecified time period (e.g. after a while) | 2 | |
| 3. Took one temperature reading after a specified time period (e.g. 5 minutes) | 4 | 11 |
| 4. Took temperature readings at regular time intervals (e.g. at five-minute intervals for 15 minutes) | 1 | 3 |

Table 1: *Pupils' performance in the planning of investigation*

| Pupils' performance while implementing their plan | Number of pupil groups | |
|---|---|---|
| | Primary 4 (N= 8 ) | Primary 5 (N= 14 ) |
| *Deviations from their original plan* | | |
| 1. Included extra steps to improve validity of the results | | |
| a. Measured the initial temperature | | 1 |
| b. Measured temperature at regular time intervals | | 3 |
| c. Used equal amount of water for all cups | 1 | 3 |
| d. Recorded time | | 1 |
| e. Emphasized adding water to the cups as quickly as possible to reduce heat loss | | 1 |
| 2. Omitted part of the steps, hence affecting validity of the results | 1 | |
| a. Failed to take time | | 2 |
| b. Forgot to take temperature readings after the specified time lapsed | | |
| | | |

| | | |
|---|---|---|
| *Introduced erroneous variables that affect the reliability and validity of the results* | | |
| Touched or held the cups in their hands frequently; stir the water with the thermometer; touched the water while waiting; took out the thermometer occasionally | 3 | 2 |
| | | |
| *Incorrect use of apparatus* | | |
| Took out the thermometer out of water to read the temperature | 2 | 1 |
| | | |
| *Manipulation of experimental procedure to match the results with their prediction* | | |
| 1. Took out the thermometer and place it in their hands to elevate the temperature | 1 | |
| 2. Extended the wait time or repeat the experiment hoping to get the predicted results. | 1 | 1 |

Table 2: *Pupils' performance in implementing their plan*

| Pupils' evaluation of experimental design and results | Number of pupils | |
|---|---|---|
| | Primary 4 (N= 37 ) | Primary 5 (N= 62 ) |
| **The design was inadequate or the results were inaccurate because:** | | |
| *1. Variables not adequately controlled .* | | |
| a. Different volume of water in different cups; | | 5 |
| b. Water not added to the cups at the same time; | | 11 |
| c. The temperature shown by the three thermometers is slightly different; should use the same thermometer for all three cups.; | | 9 |
| d. The cups were of different thickness, size, or width; | 4 | 1 |

| | | |
|---|---|---|
| e. Influence of the environment, e.g. a fan on the ceiling, air-conditioning; | 3 | 2 |
| f. Should not hold the thermometer with hands while waiting | 1 | |
| | | |
| *2. Technical errors* | | |
| Spilling of water onto the table while pouring water into the cups; difficult to read the thermometer accurately; too much delay in handling the hot water due to excessive arguing over the procedure; inaccurate measurement of volume of water | 4 | 1 |
| | | |
| *3. Quality of data* | | |
| Failed to measure the initial temperature | | 2 |
| | | |
| *4. Inconclusive nature of the task* | | |
| Argued to use more cups for comparison; inconclusive to use three cups only | | 1 |
| | | |
| *5. Results not consistent with pupils' own predictions* | | |
| The observed results were not the same as pupils' predicted results. | | 9 |
| | | |
| **The design was adequate or the results were accurate because:** | | |
| 1. No reason given | 6 | 10 |
| 2. Fit with pupils' preconception (e.g. hard plastic is not a good conductor) | 4 | 1 |
| 3. Good design; results would not be affected by other factors; | | 1 |
| 4. Took measurements with measuring instruments, predominantly thermometers | 9 | 13 |

| | | |
|---|---|---|
| 5. Good quality of data (Measure temperature at regular intervals) | | 2 |
| 6. Support from common sense reasoning (The cups are made of different materials, therefore there should be a difference in the results.) | | 5 |
| 7. Personal attributes (E.g. We worked very carefully and systematically.) | 1 | 1 |
| 8. Misconception of the nature of scientific inquiry (It must be accurate because it is an experiment.) | 3 | |
| | | |
| **Further improvement to experimental design to improve the validity and reliability of the results** | | |
| a. Lengthen the time of observation | 3 | 2 |
| b. Use hotter water (e.g. 100°C) | 1 | 2 |
| c. Add more water to each cup | | 2 |
| d. Test other cups made from different materials | 2 | |
| e. Can use my own hand instead of the thermometer to measure temperature (Primary 4) | 1 | |
| f. Use a lid to cover the cups | 5 | |

Table 3: *Pupils' evaluation of experimental design and results*

## Data analysis and discussion

*Pupils' plans*

As far as planning is concerned, pupils showed considerable limitation in measuring the dependent variable. Most pupils failed to measure the initial water temperature. As shown by the observers' notes, one reason is that at least some pupils did not realize that they needed to have some measures to indicate the rate of heat loss so that they could compare the ability of different cups in keeping warm with sufficient validity.

Another reason is that many pupils assumed that the initial water temperature was the same for all cups since they used the same hot water. In comparison, Primary 5 pupils seemed to have a better understanding of how to design measurements to obtain more valid and reliable results. More Primary 5 than Primary 4 pupils took readings at regular intervals, demonstrating an initial grasp of the concept of rate of heat loss. There was also evidence that pupils' prior understanding of science concepts was influential when planning investigations. A few Primary 4 pupils thought that keeping warm meant elevation of water temperature rather than slowing the decrease in temperature.

As to the control of variables, the results show that Primary 5 pupils seemed to be more aware of the factors needed to be controlled than their Primary 4 counterparts since a slightly greater proportion of pupils in this grade level recognized the need to control the volume of water used in each cup. However, most pupils did not mention other relevant variables such as the place where they put the cups. It was noticed that some pupils placed the cups on different materials, like the table or a plastic tray.

*Implementation of the plans*

The results show that many groups did not adhere strictly to their plans and tended to make ad hoc decisions on certain steps. This could be due to their lack of experience in conducting investigations, hence limiting their foresight in planning. Primary 5 pupils were in general more able to introduce ad hoc steps to improve the validity of their data (e.g. by measuring the initial water temperature) and to control variables like the volume of water used for each cup.

Many pupils tended to manipulate the experimental set-up with their hands while waiting for results, which inevitably introduced other variables to the experiment. This was more common in Primary 4 than in Primary 5, presumably due to their lower level of maturity. A possible explanation of this kind of behaviours is that these young pupils tended to use their own senses to check the changes in the experiment, like how hot or how cool the water became at a particular moment. However, they did so without realizing that this is at odds with the nature of scientific inquiry which emphasizes a high degree of objectivity in measuring and the need to control variables in order to ensure reliability and validity. Another interesting phenomenon reflected by the findings is that a few groups of pupils were so insistent on their predictions that they had tried to manipulate the experimental procedure to obtain more "desirable" results. Again, this may be explained in terms of different levels of maturity of the pupils and their limited understanding of the purpose of scientific investigation. It also underscores the persistence of pupils' preconceptions and the influences of these preconceptions on their learning.

*Pupils' evaluation*

The results show that primary pupils were able to reflect on their experiences in investigations, which is an important attribute of scientific thinking. Both Primary 4 and 5 pupils were not short of ideas about how to improve their experimental design based on their previous trials. It appears that Primary 5 pupils were more logical than their Primary 4 counterparts in their reasoning. A greater proportion of Primary 5 pupils were able to suggest additional variables needed to be controlled, for example, the thermometers used should be comparable with each other, and equal volumes of water should be used for each cup. It is quite interesting to observe that Primary 5 pupils were more prone to adhere to their own predictions than Primary 4 pupils even though the observed data indicated otherwise. As a result, these pupils tended to come up with different hypotheses to explain their seemingly "anomalous" results. For instance, they attributed the differences in final temperature between different cups to heat loss while water was poured out, or to the fact that the thermometers were immersed at different depths in different cups. This finding seems to contradict the argument that older pupils should be more sophisticated in scientific reasoning than younger ones. Further investigation is needed to confirm this finding.

Those pupils who considered that the results were accurate tended to attribute this to the use of instruments for taking measurements, particularly thermometers, and to a much lesser extent, measuring cups. This indicates that some pupils seemed to have a preconception that these measuring instruments were of utmost importance to getting valid results, to the extent that they were fool-proof. Even more note-worthy is the misconception of a few Primary 4 pupils that the results of science experiments must be accurate, reflecting stereotyped reasoning. This is akin to what Driver et al (1996) referred to as "blind authority". This type of reasoning seems to be characteristics of what researchers described as "phenomenon-based reasoning" in which reasoning is based on surface phenomena rather than on a more in-depth consideration of the evidence presented (Driver et al. 1996; Tytler and Peterson 2004). Pupils also went further to suggest improvements to the task. One Primary 5 pupil commented that the number of cups for testing should not be limited to three. This was echoed by two

Primary 4 pupils who suggested that other cups made from different materials should also be tested. There were other suggestions which seemed to be based on some sorts of reasoning though not explicitly spelt out, like using more water in each cup, using hotter water at the beginning of the experiment, and covering the cup with a lid.

## Conclusion

The above analysis represents only a tentative account of the insights drawn from the present study. There are certainly limitations in drawing conclusions at the present stage particularly with such a small sample size and a narrow context of investigation. Nevertheless, our analysis seems to indicate that there are considerable limitations in pupils' understanding to allow them to make thorough plans with sufficient reliability and validity. However, there is evidence that Primary 4 and 5 pupils have at least some understanding of the need to control variables. There are also indications that primary pupils could come up with ad hoc ideas while they are implementing the task probably because they need concrete stimuli to prompt them to think and make decisions as to how to carry out the task. While intuitive thinking is still obvious in many primary pupils, the present study has yielded some evidence to support that pupils' cognitive understanding related to science investigations progresses with age as reported in other research studies (Gott and Duggan 1995; Millar et al. 1994). These findings seem to imply that upper primary pupils starting from Grade 4 are quite ready to conduct scientific investigation, probably with the guidance of their teachers. It seems likely that their reasoning skills could be improved when more experiences are provided to further their understanding of the nature and purpose of investigation, and of the kind of evidence needed to provide valid and reliable conclusions. However, it is difficult to generalize the present findings to the whole pupil population in Primary 4 and 5 in Hong Kong because of the small and uneven sample size. More research is needed to validate these findings, and to find out whether similar patterns exist in other contexts of scientific inquiry.

# References

Adey, P. (1998). Children's thinking and science learning. In M. Ratcliffe, *ASE guide to secondary science education* (pp. 67-73). Hatfield: Association for Science Education.

Adey, P. Shayer, M. et al. (2001). *Thinking science*. Cheltenham: Nelson Thornes.

Ausubel, D. P. (1968). *Educational Psychology: A cognitive view*. East Bourne, East Sussex: Holt, Rinehart and Winston.

Bruner, J. S. (1960). *The process of education.* Cambridge, Mass.: Harvard University Press.

Curriculum Development Council (2002a). *General Studies for Primary Schools Curriculum Guide (Primary 1 -Primary 6)*. Hong Kong: Curriculum Development Council.

Curriculum Development Council (2002b). Science Education: Key Learning Area Curriculum Guide *(Primary 1 - Secondary 3)*. Hong Kong: Curriculum Development Council.

Curriculum Development Council (1998). *Science: Secondary 1-3.* Hong Kong: Curriculum Development Council.

Driver, R., Leach, J., Millar, R., & Scott, P. (1996). *Young people's images of science*. Milton Keynes: Open University Press.

Etheredge, S. & Rudnitsky, A. (2003). *Introducing students to scientific inquiry: How do we know what we know?* Boston: Pearson Education.

Gagne, R. M. (1985). *The conditions of learning and theory of instruction*. Holt-Saunders.

Gott, R. & Duggan, S. (1995). *Investigative work in the science curriculum*. Buckingham: Open University Press.

Gott, R., Duggan, S., and Roberts, Ros. (2003). Research into understanding scientific evidence. Retrieved September 15, 2004, from University of Durham Web site: http://www.Dur.ac.uk/Richard.gott/Evidence/cofev.htm

Gott, R. and Murphy, P. (1987). *Assessing Investigation at Ages 13 and 15. Science Report for Teachers: 9*. London: HMSO.

Inhelder, B. & Piaget, J. (1958). *The growth of logical thinking from childhood to adolescence*. London: Routledge and Kegan Paul.

Kanari, Z. (2000). Children's performance in tackling science investigations and their reasoning about evidence (D. Phil Thesis). York:University of York.

Lawton, D. (1978). Why change the curriculum? In D. Lawton, P. Gordon, M. Ing et al. (Eds.), *Theory and practice of curriculum studies*. London: Routledge & Kegan Paul.

Lee, Y. C. (2003). *An evaluation of the new junior secondary science curriculum in Hong Kong* (PhD Thesis). London: University of London Institute of Education.

Millar, R., Lubben, F. et al. (1994). Investigating in the school science laboratory: conceptual and procedural knowledge and their influence on performance. *Research Papers in Education - Policy and Practice, 9*(2): 207-248.

O'Loughlin, M. (1992). Rethinking science education: Beyond Piagetian constructivism toward a sociocultural model of teaching and learning. *Journal of Research in Science Teaching, 29*, 791-820.

Shulman, L. S., & Keislar, E. R. (Eds.). (1966). *Learning by discovery: A critical appraisal*. Chicago: Rand-McNally.

Strang, J., Daniels, S. & Bell, J. (1991). *Assessment matters No. 6: planning and carrying out investigations*. London:SEAC.

Tytler, R. & Peterson, S. (2004). From "try it and see" to strategic exploration: Characterizing young children's scientific reasoning. *Journal of Research in Science Teaching, 41*(1), 94-118.

Watson, R and Wood-Robinson, V. (1998). Learning to investigate. In M. Ratcliffe (Ed.), *ASE guide to secondary science education* (pp.84-91). Hatfield: Association for Science Education.