THE PROMOTION OF THINKING IN SELECTED LOWER SECONDARY SCIENCE CLASSROOMS IN TRINIDAD AND TOBAGO:
Implications for Teachers' Education

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This article reports on a study into the levels of thinking promoted in selected lower secondary science classrooms in Trinidad and Tobago. Twenty-seven teachers, 10 of whom were professionally certified, were observed twice. The levels of thinking were inferred from an analysis of teaching/learning strategies, teachers' and students' questions, the process skills used, and types of classroom interactions. The findings indicate that the teachers, both professionally certified and uncertified, were unable to promote higher-order thinking in their classrooms. There are implications for teacher education programmes.

Introduction

The development of students' thinking is an educational goal that is receiving renewed attention. From the United States of America (USA), Feiman-Nemser (2001, p. 1051) reports that "many contemporary reforms call for content-rich, learner-centred teaching, which emphasizes conceptual understanding and gives all students opportunities to think critically, solve problems, and learn things that matter to them and have meaning in the world outside of school." However, the research shows that significant proportions of high school and university students are unable to engage effectively in activities that require higher-order cognitive functioning (see Beyer, 2001a).

In Trinidad and Tobago, the country in which this study was conducted, many teachers, employers, and stakeholders also express the view that the students/graduates of the secondary education system, including science graduates, are unable to think critically. Most seem to operate at low-order cognitive/mental levels (knowledge and comprehension) as

identified by Bloom, Englehart, Furst, Hill, and Krathwohl (1956), where they can recall information and explain concepts and principles, but are unable, for example, to critically examine ideas/concepts, solve problems, and make reasoned arguments. The crucial question is: Are our secondary science teachers, providing the kinds of experiences that would facilitate the development of these higher-order thinking processes/operations?

The Context

Trinidad and Tobago, a twin-island republic, is located in the southern Caribbean. In keeping with international trends, Trinidad and Tobago is also currently involved in educational reform. At the secondary level, the reform initiative is described as the Secondary Education Modernization Programme (SEMP). The SEMP began at the lower secondary level—the first three years of secondary schooling—with the development of curricula in seven core areas, including science. Students at the lower secondary level may range in age from 11 to 17 years. They begin their lower secondary schooling in Form 1, moving on to Forms 2 and 3 over a 3-year period.

Included among the expected learning outcomes of the SEMP science curriculum are that students will "interpret and evaluate data," "critically reflect on and interpret ideas presented through a variety of media," (Trinidad and Tobago. Ministry of Education [T&T], 2003, p. 1-9), "reflect critically on ethical and other issues" (p.1-10) and "develop a critical awareness of the role of science in everyday living" (p. 2-1).

Underpinning these outcomes is the assumption that the experiences provided in the science classroom have the potential to facilitate/promote thinking. This assumption has been the impetus for a number of research activities outside of Trinidad and Tobago (Adey & Shayer, 1994; Zimmerman, Raghavan, & Sartoris, 2003) investigating the kinds of approaches used to develop thinking skills, or the effectiveness of various interventions on the development of thinking. This type of research has not been conducted within Trinidad and Tobago, and, therefore, this survey is the first of its kind within the country that seeks to gather empirical data on the approaches that have the potential to promote higher-order thinking in science classrooms, as required by

SEMP documents and in light of the unique circumstances described below.

In Trinidad and Tobago, the teachers at the secondary level do not all have professional certification. It is not a requirement for entry into the teaching service, as obtains in other countries, for example, the USA and the United Kingdom (UK). It means, therefore, that both professionally certified teachers (hereafter referred to as trained teachers) and uncertified teachers (hereafter referred to as untrained teachers) are expected to enact the curricula, including the science curriculum. The professional certification offered to graduate teachers at the secondary level is the one-year in-service Postgraduate Diploma in Education (Dip.Ed.) programme offered at the St. Augustine Campus of The University of the West Indies (UWI). The programme involves face-to-face sessions at the campus and field visits to schools.

An eclectic model, which draws on aspects of teacher behaviour development (see Koballa, Jr. & Tippins, 2001) and reflective practice, underpins the prospectus for the Dip.Ed. programme. For example, "The programme attempts to ensure that classroom practice is informed by a solid theoretical base in the foundation disciplines, curriculum theory, and methodology" (The University of the West Indies [UWI]. School of Education, 2004, p. 63). The objectives of the programme include the following:

- encourage teachers to give the greatest attention to past and present practices and future possibilities in the teaching of their subjects;
- lead teachers to consider the professional implications of the nature of their occupation and to strive for continued professional growth. (p. 63)

Guided by the stated objectives, the science teacher educators develop the course outline before the programme begins. During face-to-face sessions, theoretical frameworks are presented and discussed, and participants suggest implications for their practice. Teachers are then expected to implement the strategy described and their efforts are monitored during the next school visit or field day. In addition, the teachers are expected to keep a reflective journal, and to submit a teaching portfolio as part of the assessment requirements. The portfolio

serves as a vehicle for self-evaluation, as it allows the teachers to reflect on their philosophies of teaching and on practice, to assess strengths and weaknesses in the professional work accomplished over the period of training, and to highlight significant growth points. They are also required to submit a formal report of an action research project that was conceived and implemented during the year.

A perusal of the prospectus reveals that there are no explicit statements that allude to the preparation of, or assessment of, teachers in the area of teaching critical thinking skills. However, during the course entitled "Curriculum Process," the science teachers are introduced to evidence-based strategies—selected by the tutors—which can facilitate the development of higher-order thinking skills. These include uses and purposes of questions, the integration of process skills in science teaching, use of practical work involving inductive and deductive approaches to concept development, and active learning strategies. Following the face-to-face sessions conducted at UWI, the teachers are expected to implement these strategies and to reflect on their developing competencies. Tutors and peers provide support and feedback through field experiences.

There is evidence that teachers' instructional practices are guided by their thinking and beliefs, which in turn affect student thinking (Brickhouse, 1990; Hashweh, 1996; Onosko, 1990). The evidence also suggests that these relationships are not simple, and that there are multiple factors that may obstruct a simple and direct influence (Zohar, 2004). One factor has been described as the ambivalent character of teachers' conceptions of thinking and teaching science—on the one hand they believe that efficient learning is realized when they transmit knowledge in an effective way, and on the other hand they believe that it is important for students to learn in an active way. Thus, there is a contradiction between teachers' conscious way of thinking about teaching and learning (which they may have acquired in a teachers' course) and a less conscious way of processing information that may be influenced by their own experiences as students (De Jong, Korthagen, & Wubbels, 1998, as cited in Zohar, 2004). Another factor that might determine whether teachers act on their beliefs is cultural traditions. These traditions shape students' perceptions of their roles in the classroom, and may frustrate teachers in their attempts to engage

students in activities that enhance higher-order thinking. For example, students may resist attempts to move them from a passive mode of learning to an active mode that encourages collaboration and interaction (Snell, 1999).

This paper reports on a preliminary survey to determine the kinds of experiences that are provided for stimulating higher-order thinking in selected lower secondary science classrooms. The lower secondary level was chosen because the recently introduced SEMP curriculum reflects a strong thinking skills focus. The findings are intended to serve two purposes. The first is to make some inferences about the levels of thinking promoted based on students' and teachers' behaviours within the science classroom. The second is to provide research evidence to inform the approach for developing strong thinking skills pedagogy in teacher education programmes.

With respect to the first purpose of the paper, the premise is made that some classroom activities/experiences facilitate low-order mental operations (low-level thinking) while others facilitate higher-order mental operations (high-level thinking). The higher-order operations, which are fundamental to scientific activity, are also referred to as "critical thinking" or the "skilled and active interpretation and evaluation of observations and communications, information and argumentation (Fisher & Scriven, 1997, p. 21, as cited in Fisher, 2001). Watson and Glaser (cited by Bitner, 1991), and Facione (1998) refer to core critical thinking skills, which include inference, recognition of assumptions, deduction, interpretation, analysis, evaluation of arguments, explanation, and self-regulation.

Higher-order mental operations (critical thinking) have informed the development as well as the interrogation of scientific knowledge, and are also inherent in the procedural aspect of scientific enquiry (the science processes). Hence, for the development of higher-order thinking, the activities in the science classroom should reflect similar foci. The literature provides direction as to the kinds of activities/experiences and teacher behaviours that facilitate thinking in the science classroom.

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Facilitating Student Thinking – A Brief Review of Related Literature

Inferences about students' thinking can be gleaned from their behaviours (Mislevy, 2004). Such behaviours include the types of questions students ask; the quality of their responses to teachers' questions; their ability to make sense of data from a number of sources, for example, discerning patterns, making generalizations, applying principles to solve problems; and making reasoned judgements based on evidence. The research suggests that there is a relationship between certain instructional strategies and thinking skills outcomes (Beyer, 2001a). For example, teachers can facilitate the development of student thinking by: (a) providing opportunities for process skill development, (b) using questioning appropriately, and (c) including collaborative classroom interaction/activities (Higgins et al., 2004).

Process skills and development of thinking

Prior to the 1980s, the term "process skills approach" was usually associated with science curricula, in which the development of general science processes was the primary goal. During the 1980s, there was much debate about the appropriateness of focusing on the teaching of general process skills with the expectation that the use of these skills would be transferred to specific domains. In a seminal paper published in 1987, Millar and Driver presented critiques of the process approach to science teaching from various perspectives—the philosophy of science, cognitive psychology, and pedagogy. Their main argument was that use of the process skills is context and domain dependent, and should be linked to the teaching of science concepts and constructs.

Certain process skills have been identified in the literature as necessary for the examination and explanation of natural phenomena. In science education, process skills are usually, but not exclusively, developed in association with practical work. By practical work is meant "any teaching and learning activity which involves at some point the students observing or manipulating real objects and materials" (Millar, 2004, p. 2). Chiappetta and Koballa, Jr. (2002) classify the science process skills as basic and integrated. Basic skills include observing, measuring, and making predictions. Some of the integrated skills are designing

experiments, developing models to explain phenomena, and interpreting information. While these skills are not exclusive to science, the integrated skills and advanced reasoning are required for scientific enquiry. All of these processes, to some extent, involve analytical thinking, which is as essential in science as critical thinking skills (Swartz & Fischer, 2001). Therefore, students who are given opportunities to use the basic and integrated process skills to enhance conceptual understanding of science are likely to be engaged in critical and analytical thinking about science content and the nature of science and scientific enquiry.

Millar (2004) cautions that student thinking about scientific enquiry does not advance much unless practical tasks are designed with specific, progressively challenging objectives in mind. It means that teachers must be cognizant of the multiple purposes of practical work. Furthermore, he states that the prevalence of the empiricist/inductivist view of science and the development of scientific knowledge—the belief that "ideas 'emerge' automatically from the event itself" (p. 11)—can limit the opportunities that teachers provide for developing thinking in and about science. In addition, students may have limited exposure to the hypothetico-deductive approach to doing science, for which the integrated process skills of hypothesizing and experimenting are required.

Questioning

According to Shakespeare (2003), arguments that support the use of questions in teaching and learning are clear and convincing, and include the roles that questions play in the development of thinking skills and in enhancing students' understanding of the nature of science. Bloom et al.'s (1956) taxonomy is perhaps the most familiar to science teachers, and many researchers acknowledge that it provides a framework for the development of questions that require varying levels of thinking (Blosser, 1990; Chiappetta & Koballa, Jr., 2002; Cotton, 1988). Costa's (2001) information processing model for questioning is less familiar, but just as useful.

Costa (2001) is of the view that "questions invite different levels of complexity of thinking" (p. 361). He refers to three levels of questioning.

The first level of questions, which is the input level, is pitched at gathering and recalling information. Questions at this level require students to recall past experiences, information, and concepts. At the second level, classified as the process level, questions should require that students make sense of the information gathered. These questions require students to determine cause-effect relationships, compare, contrast, analyse, summarize, and synthesize data. The third level is described as the output level, requiring students to apply and evaluate actions in novel situations. Questions pitched at the output level require students to think creatively and hypothetically, use their imagination, expose their value systems, and make judgements. While there are some similarities between Costa's levels of questions and Bloom's taxonomy, Costa identifies the thought processes required for each of his levels, thus explicitly relating questioning to levels of thinking.

The research evidence (e.g., Blosser, 1990) shows that teachers tend to pose questions at low levels of Bloom et al.'s (1956) taxonomy, so that students operate mainly at the knowledge and understanding levels (the input level in Costa's model). It also shows that even when teachers attempt to challenge students to engage in higher mental operations by asking probing questions, "wait-time" is usually very short (Chiappetta & Koballa, Jr., 2002; Costa, 2001). The seminal work of Rowe (2003) in the area of questioning has shown that increased wait-time results in an increase in the level of cognitive functioning. There is also evidence that redirection/probing/reinforcement, use of higher-order questions, and lengthening wait-time not only enhance thinking skills, but are also associated with increases in student engaged time and level of participation (see Cotton, 1991).

Increased levels of cognitive functioning, which can be determined by a comparison over time of student performance on tasks designed to challenge their thinking and reasoning, are also facilitated when students ask questions, especially higher-order questions. These higher-order questions, also referred to as "quality questions," are reflective of critical thinking and they also facilitate the development of critical thinking skills (Fisher, 1990, as cited by Alsop, de Jesus, & Watts, n.d.). However, research on classroom questions indicates that teachers do not select the types of strategies that encourage student questions during classroom sessions (Chin, 2004). For example, problem solving has been

shown to elicit more, and a wider range of, students' questions at the higher-order level than teacher-directed activities (Chin, Brown, & Bruce, 2002).

Classroom interactions

There is some theoretical support for the view that the development of thinking is facilitated by social interaction (Leach & Scott, 2000; Vygotsky, 1978). As applied to the classroom context, the literature reveals that one-way interaction, such as the lecture method, produces the least benefits in terms of acquisition of cognitive skills and strategies. On the other hand, student-centred types of classrooms in which there is a variety of interaction patterns, and where students are, for example, working cooperatively in groups to make decisions, collecting data by hands-on manipulation of material, constructing strategies to solve problems, and validating solutions based on student-generated data, produce the highest output in terms of complex thinking processes (Costa, 2001; Johnson & Johnson, 2001). Furthermore, the literature suggests that classroom interactions should optimize opportunities to develop communities of inquiry, since these can assist in the development of students' thinking and learning through social interaction and reflective inquiry (Kovalainen, Kumpulainen, & Vasama, 2001).

Conceptual Framework and Methodology

Levels of thinking promoted in the lower secondary classroom were examined through an analysis of the teaching/learning strategies, the questions asked by students and teachers, the range of science process skills (basic and integrated) implemented, and the patterns of classroom interactions, (see Figure 1).

The following research question informed the study:

- What levels of student thinking are promoted in the lower secondary science classroom in Trinidad and Tobago?
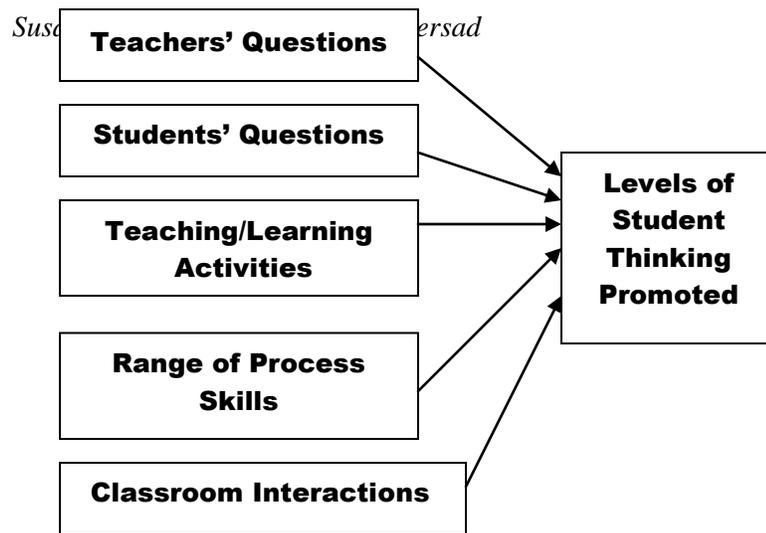
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Figure 1. Activities/experiences linked to promotion of student thinking.

The sample, data collection, and analysis

A total of 27 science teachers participated in the study. The participating teachers were a heterogeneous group, which was differentiated by professional certification and years of teaching experience. Of the 27 participating teachers, 10 were trained and the others were untrained. Trained and untrained teachers were purposely included to determine to what extent teachers spontaneously include higher-order thinking experiences in their repertoire. The study was conducted over a 3-month period. The data collection strategy was classroom observations at each of the three lower secondary class levels.

Four researchers, who were science education lecturers on the Dip.Ed. programme at UWI, were involved in data collection. Each science teacher was observed while teaching on two occasions. The lessons were audio taped, transcribed, and summarized to highlight key episodes in terms of teachers' actions and students' actions. The data were further analysed using the following pre-established frameworks—Bloom et al. (1956) and Costa (2001) for analysis of questions, and Chiappetta & Koballa, Jr. (2002) for categorizing science process skills. Open coding of data, followed by thematic clustering, was used to categorize classroom interactions and teaching/learning activities.

There are two limitations of this study. One was that each teacher was observed on two occasions only. While this small number of lessons observed may not reflect typical teacher behaviour, the observations do give some insights into classroom practices. The second is that all inferences made about students' thinking outcomes were based only on classroom observations, since students' written work was not available for analysis.

Findings

The findings are presented under the following headings: teaching/learning strategies, teachers' and students' questions, and range of process skills developed. Comments on the types of interactions associated with specific strategies are embedded in the analysis. The findings are presented not only in terms of the potential of selected strategies to promote higher-order thinking, but also in relation to the effectiveness of teacher behaviours to facilitate same.

Teaching/learning strategies

Table 1 shows the teaching strategies used by the sample of teachers observed. As illustrated in this table, teaching strategies were categorized according to their potential for promoting higher-order thinking. The results indicate that the proportion of trained teachers using the five strategies that could definitely promote higher-order thinking was high for one category (probing questions), medium for three categories, and low for one category. The proportion of untrained experienced and untrained inexperienced teachers using these strategies was low for four of the five categories, and medium for one. Overall, a higher proportion of the trained teachers used strategies that had the potential to definitely promote higher-order thinking than the untrained teachers.

Six of the strategies were categorized as having the potential for possibly promoting higher-order thinking. The proportion of trained teachers using these strategies was high for two of the categories (small-group activities and practical activities), and medium for four. The strategy used by a high proportion of untrained experienced and untrained inexperienced teachers was the use of textbooks.

Table 1. Strategies used by Lower Secondary Science Teachers for Delivering Instruction

Strategy	Potential for Promoting Higher-order Thinking	Frequency/ Proportion of Trained N = 10	Frequency/ Proportion of Untrained Experienced N = 7	Frequency/ Proportion of Untrained Inexperienced N = 10	Total frequency
Use of Ss past experiences	Definitely	6 (medium)	4 (medium)	3 (low)	13
Questioning (probing)		7 (high)	1 (low)	3 (low)	11
Wait-time strategy		5 (medium)	1 (low)	3 (low)	9
Linking new concepts		4 (medium)	1 (low)	3 (low)	8
Analogies		3 (low)	0 (low)	3 (low)	6
Use of textbook	Possibly	5 (medium)	6 (high)	7 (high)	18
Small-group activities		9 (high)	2 (low)	3 (low)	14
Practical activities		9 (high)	2 (low)	2 (low)	13
Demonstration		5 (medium)	2 (low)	3 (low)	10
Use of visual aids		4 (medium)	2 (low)	3 (low)	9
Discussion		5 (medium)	2 (low)	1 (low)	8
Questioning (recitation)	Marginally	6 (medium)	6 (high)	9 (high)	21
Lecturing /teacher presentation		4 (medium)	7 (high)	7 (high)	18
Copying/ reading/ collecting notes		6 (medium)	2 (low)	8 (high)	16

Key: For N = 10, 7 - 10 = high, 4 - 6 = medium, 0 - 3 = low
For N = 7, 5 - 7 = high, 3 - 4 = medium, 0 - 2 = low

With the exception of the use of textbooks, the proportion of untrained experienced teachers using the other strategies in this category was low. What is noteworthy is that a medium proportion of untrained inexperienced teachers used demonstrations and visual aids, which was not evident with their experienced colleagues. This was an example of untrained inexperienced teachers spontaneously or intuitively using strategies that could possibly promote higher-order thinking.

Conversely, all the strategies categorized as having the potential to marginally promote higher-order thinking were used by a high proportion of untrained teachers in both groups, with the exception of copying notes. A medium proportion of trained teachers used these strategies. It is evident that a higher proportion of untrained teachers selected those strategies that had the potential to marginally promote higher-order thinking.

A critical analysis of how some of the strategies were used, and the extent to which the potential for developing higher-order thinking was realised, follows.

The most frequently used strategy was the quick-paced question and answer sequence (recitation)—that is, initiation, response, feedback sequence, generally referred to as IRF (Sinclair & Coulthard, 1975), which involved two-way interaction. The following examples illustrate:

T: What are some examples of organisms that show asexual reproduction?
S: Amoeba.
T: Amoeba. Very good.
S: Algae.
T: Some algae, what else?

T: The last thing we did was blood vessels. You all recall that? What are the three types of blood vessels?
S: Arteries, veins, capillaries.
T: What do arteries do?
S: Carry blood away.
T: Most arteries carry blood away from the heart. What about that blood?
S: What was the question?
T: If you remember the structure of the heart, left and right…

The lecture method was the second most frequently used strategy. This involved one-way interaction in which students were passive recipients. Practical work was the next most common strategy adopted. This involved interaction between students and manipulatives. Of these three dominant strategies, only practical work provided the kinds of experiences that had the potential to possibly promote higher-order thinking.

Practical work was included in 22 of the 54 lessons observed. Six of the trained teachers and four of the untrained experienced teachers implemented verification laboratory activities, either as group activities or as demonstrations. The main intent of these sessions was to confirm principles and concepts that had been discussed in a previous class. For example, after a series of lessons on balancing equations, the mole concept, and neutralization reactions, an untrained, experienced teacher took the students into the laboratory to engage in procedures to verify the concepts. The students were therefore involved in deductive reasoning. In some cases, the teachers attempted to take the exercise further by having students apply the concepts to solve a problem. On these few occasions, the students were given opportunities to think at Bloom et al.'s (1956) level of application or Costa's (2001) process level.

In contrast, only three trained teachers and one untrained experienced teacher involved their students in inductive reasoning for concept development, during laboratory activities that would have required students to make inferences based on a series of observations or data in order to make generalizations. In one case, students were provided with apparatus and materials, and through questioning and analysis of data were led to induce Hooke's law. These are examples of experiences where there was the potential for students to operate at Costa's (2001) output level. During another laboratory activity, students did calculations of surface area/volume ratios using samples of cheese, and then made inferences with respect to surface area and rate of absorption in the small intestine and in the lungs. These latter are examples of Costa's process level of thinking.

There were a few occasions when teachers used analogies, visual aids/models, concept mapping, and the learning cycle (which involves

exploration, introduction, and application of concepts). These less-frequently seen strategies, during which students were operating at Costa's (2001) process level, were used by trained and untrained teachers alike, and provided opportunities for students to make linkages, compare, look for patterns, apply principles, and make inferences. For example, an untrained teacher used students' prior knowledge of pressure and water pumps at the local water authority—the Water and Sewage Authority (WASA)—to make the link between the structure of the heart (muscular walls) and its functions in withstanding pressure. An example of the learning cycle strategy involved the use of a model to represent airflow in a system as a result of a pressure differential. Students were given opportunities to compare the parts of the model with the respiratory system. They then applied the principles behind the operation of the model to the mechanism of breathing in the lungs. In the latter two cases, a high level of thinking was being promoted since students were required to operate at Costa's output level, that is, to look for patterns, derive generalizations, and make judgements based on evidence. These opportunities for thinking at this level were, however, the exception instead of the rule.

Teachers'/students' questions

The lower secondary science teachers asked a variety of questions. These questions were predominantly of the low-level type, and teachers used them in various ways. One use of questions was to find out what students had learnt either during the lesson or from a previous lesson. For example:

> What is a hormone? What are some examples of hormones you know?

> What kinds of bonding occur between atoms?

In such cases, students' responses were short, quick, and knowledge-based. For example, in response to the question requesting examples of hormones, students' responses included insulin and adrenaline. They were not required to engage in any extended mental processing before responding, since their responses were immediate and they were simply recalling information held in memory. They were operating at Bloom's level of recall or the level referred to by Costa (2001) as the input level.

The teachers also used questions to identify gaps in students' knowledge, to draw attention to misconceptions, or to link existing prior knowledge to new learning. The examples below from an untrained teacher and a trained teacher illustrate the latter. After a discussion on the structure and function of arteries and veins, the untrained inexperienced teacher wanted the Form 3 students to make an inference about the structure of capillaries based on the pre-established functions. In an attempt to have students operate at Costa's (2001) process level, she asked:

What do you think the structure of the capillary would look like?

After the question was posed, the students did not respond immediately. The teacher was then unable to provide the necessary follow-up questions and scaffolds, and instead resorted to giving the information herself. This was an example of ineffective teacher behaviour.

During a lesson on food webs with a Form 1 class, a trained teacher attempted to elicit from students various sources of food for a selected organism in a food chain. He mentioned that the chain was becoming complex or "tangled-up." He then tried to use students' knowledge of ducks' webbed feet to introduce the concept of interrelationships among the chains that comprise a food web. However, the teacher did not use probing questions to have one of the students make her reasoning more explicit, and, hence, was unable to effectively facilitate the use of analogical thinking as intended. The following represents the exchange between the teacher and the student:

T: Think of the duck's feet. What's between?
S: Toes, phalanges.
T: Define the term *food web* in terms of food chains. What does it show us?
S: It shows what feeds on what.
T: Is there any connection?

A similar pattern of teachers' inability to use probing questions, or to scaffold students' ideas was apparent during a lesson on vegetative propagation and cloning with Form 3 students. The untrained inexperienced teacher presented explanations on different forms of plant clones. A student asked the question: What is tissue culture? The teacher then posed this question to the class: "What do you think tissue culture might mean?" The students did not respond after appropriate wait-time, and the teacher gave an explanation of the process. It was evident from

her follow-up explanations that she was hoping that the students would have been able to make a link between bacterial cultures growing in a medium (that had been previously discussed) and this new concept of tissue culture. However, the teacher lacked the skills to ask the kinds of probing questions that would enable the students to think at Costa's (2001) process level in order to make this connection, and thus to bridge the gap in understanding of the cloning process. This pattern was also observed with untrained experienced teachers.

The majority of teachers who asked probing questions used wait-time effectively. But even on these few occasions, the teachers were unable to probe effectively to have students make their explanations more robust. The following is an example of how one trained teacher attempted to use probing questions, which would have allowed students to operate at Costa's (2001) output level, that is, to make an evaluation or prediction, or develop a hypothesis during a lesson on the characteristics of a scientist. After giving short narratives on the contributions of some scientists (Democritus, Dalton, Thompson, and Rutherford) to the development of the atomic theory, he asked the following questions:

What does all that suggest?

If we look at the time?

It is highly likely that his intention here was to have the students synthesize the information in order to look for patterns in the development of the atomic theory. For example, the students could have focused on the use of confirmatory evidence to build the theory, or on evidence that may have disconfirmed the existing theories and resulted in a change of thinking. Rather than continue with this line of questioning after an unexpected response from the student, which was "It had scientists in Jesus' time," he proceeded to change the line of questioning as follows:

T: What did it take to become a scientist?
S: Hard work.
T: Why was it hard?
S: Because they had to search for answers.
T: And what does that involve?
S: Being able to know what the answer is.
T: Yes. But in doing that what do you need?
S: Patience, time, investigation, instruments.

The line of questioning did not really challenge the student to make any inferences about the qualities of scientists, for example, being open-minded (willing to change ideas and theories in the light of new evidence), or persevering (willing to take tasks to a conclusion), or curious (a disposition to investigate). In this example, the second question does not provide a scaffold for the student to extend his understanding of the concept of *hard work* as it applies to a scientist. Instead, after the student's response to the first question, the teacher might have asked "Can you give some examples of ways in which any one of the scientists demonstrated that he was engaged in hard work?" This line of questioning would have challenged the student to reflect on his understandings of the nature of scientific work, and to understand more fully why he described scientific work as "hard." The assumption here is that the teacher intended to have the student give examples and then match the examples with evidence from the narrative. In this way, the teacher would have interrogated the students' understandings of the work of scientists, and would have helped them to discern the relationship between science and the qualities of the scientist, and the relationship between evidence and formulation of theory.

Little attention was given to providing a forum for students' ideas about the particular science concepts under examination or to the generation of students' questions in relation to science phenomena. Students' questions, which were significantly fewer than their teachers' (1:10), were pitched mainly at the levels of knowledge and comprehension (Bloom et al., 1956). Examples of low-order questions include "What are cuttings?" in a lesson that dealt with vegetative propagation, and "This is the same displacement?" (Translation: Is this another example of a displacement reaction?*)* in a lesson that dealt with types of chemical reactions.

However, students did ask a higher percentage (25%) of higher-order questions, compared to their teachers (14%). In most cases, the higher-order questions posed by students were not handled satisfactorily by the teachers. For example, during a lesson on blood circulation, a male student sought some explanations on what seemed to be a discrepancy. The untrained, inexperienced teacher had referred to wrist slashing as a common method of suicide. This immediately seemed to result in

cognitive conflict for the student, who asked: "Miss, and they does cut off people hand?" (Translation: Miss, don't surgeons amputate people's hands?). The implied reasoning here seemed to be that since people do not die from amputations then they should not die from wrist slashing. The teacher, however, did not respond to the question; hence, there was no resolution for the student. Most importantly, however, it was a missed opportunity for engaging not only the student but also the entire class in high-level cognitive operations, by use of probing questions that would have allowed for comparing and contrasting the two procedures (what occurs in a controlled environment, such as tying off blood vessels during surgery to prevent blood loss, versus what occurs in an uncontrolled situation), as well as looking for patterns and significant differences (Costa's (2001) process level).

In summary, it was noted that trained and untrained teachers were unable to use questioning effectively. It was significant that three trained teachers resorted to use of low-level questions only and that trained teachers were unable to manage unexpected responses from students. While the trained teachers asked a higher percentage of higher-order questions than the untrained teachers, this percentage was very low (less than 25% of all the questions that they asked). In addition, untrained teachers did not deal satisfactorily with students' higher-order questions. As outlined earlier, the literature suggests that higher-order questions posed by both teachers and students play an important role in students' cognitive engagement and, by extension, in their thinking. It was evident that the teachers observed were not paying sufficient attention to the asking or eliciting of higher-order questions.

Range of process skills

Table 2 shows the range of process skills promoted in the classrooms observed. Chiappetta and Koballa, Jr.'s (2002) framework for classifying process skills as basic and integrated was used. The latter requires higher-order thinking. All of the teachers observed implemented activities that gave students opportunities to use some of the basic process skills such as, observation, use of numbers, inferring, measuring, and predicting.

Table 2. Process Skills Used in Lower Secondary Science Classrooms

Process Skills	Frequency/ Proportion of Trained Teachers N = 10	Frequency/ Proportion of Untrained Experienced N = 7	Frequency/ Proportion of Untrained Inexperienced N = 10	Total Frequency
Basic Skills				
Observing	8 (high)	7 (high)	7 (high)	22
Inferring	7 (high)	3 (medium)	1 (low)	11
Measuring	7 (high)	2 (low)	1 (low)	10
Using numbers	5 (medium)	3 (medium)	1 (low)	9
Data gathering	5 (medium)	2 (low)	1 (low)	8
Predicting	3 (low)	1 (low)	0 (low)	4
Classifying	2 (low)	0 (low)	0 (low)	2
Space/time relation	0 (low)	0 (low)	1 (low)	1
Integrated Skills				
Communicating	10 (high)	5 (high)	5 (medium)	20
Experimenting	7 (high)	2 (low)	1 (low)	10
Interpreting data	3 (low)	2 (low)	0 (low)	5
Defining operationally	2 (low)	0 (low)	0 (low)	2
Hypothesizing	1 (low)	0 (low)	0 (low)	1
Formulating models	0 (low)	0 (low)	0 (low)	0
Controlling variables	0 (low)	0 (low)	0 (low)	0

The skill of observation received attention from a high proportion of trained and untrained experienced teachers, and a medium proportion of untrained inexperienced teachers. The development of this basic process skill was evident in 22 of the 54 science lessons during short activities that formed part of a set induction, a demonstration, or a group activity. For example, an untrained experienced teacher demonstrated the difference in reactivity of metals (magnesium, zinc, and copper) with dilute acids to her Form 3 students. They observed the reaction between the metal and the acid, and measured the volume of gas produced over time to determine the rate as a measure of reactivity of the metal. A

trained teacher began his Form 1 integrated science class on the expansion and contraction of substances by asking students to make predictions about the effect of heat on the metal ball. He then demonstrated the effect using the ball and ring apparatus. He further developed the concept by asking his students to make similar predictions about the expansion of liquids and gases.

Unfortunately, the opportunities for students to engage in complex thought processes during these activities were few. This was due either to poor task management or teachers' inability to use probing questions to help students to interpret what they were doing, why they were doing it, and what was the relevance to their everyday lives. Instead, the discussions focused primarily on the data collected and quantitative measures rather than, for example, on the relationship between evidence and explanations described by Millar (2004) as linking the two domains of knowledge: domains of objects and observables with that of ideas. In addition, there were few attempts to have students apply the information gleaned to solve problems in a new setting. Consequently, students were engaged most of the time in low-level thinking.

Teaching to facilitate use of integrated skills was sometimes seen (see Table 2). The integrated skill of communication was the only one that was used by a high or medium proportion of all categories of teachers. The only other integrated skill that received attention from a high proportion of trained teachers was experimenting. The proportion of all categories of teachers who included the other integrated skills was low. These integrated skills require the use of complex processes that characterize higher-order thinking. Unfortunately, teachers did not focus sufficiently on including experiences requiring the use of integrated process skills, which provide opportunities for students to give explanations, to ask questions, to adopt a new idea, or to highlight a discrepancy, all of which are examples of higher-order thinking behaviours.

Conclusion/Discussion

This paper was intended to serve two purposes—to make inferences about the levels of thinking promoted in the science classrooms observed, and to provide research evidence to inform the approach for

developing strong thinking skills pedagogy in teacher education programmes. The discussion addresses each purpose in turn.

With regard to the levels of thinking promoted, the findings indicate that, in general, higher proportions of the trained teachers selected strategies that either definitely or possibly had the potential to promote higher-order thinking than their untrained colleagues. Conversely, higher proportions of untrained teachers selected strategies that marginally had the potential to promote higher-order thinking than their trained colleagues. However, when all of the data on teachers' and students' behaviours are combined, it is evident that the lower secondary science classrooms observed were characterized by low levels of thinking. In sum, the patterns of interactions, the levels of teachers' questions, the paucity of students' questions, the choice of teaching strategies, as well as the limited range of process skills utilized all give rise to concerns.

The interactions in the classrooms of both trained and untrained teachers generally did not reflect the types of collaboration that could facilitate critical and creative thinking as well as reflective inquiry, as suggested by Kovalainen, Kumpulainen, and Vasama (2001). There was also a predominance of low-level teachers' questions that required thinking at Costa's (2001) input level. The teachers observed did not optimize the use of questions to probe students' responses and extend their thinking to higher cognitive levels. In addition, they did not use strategies that could encourage students' questions. For example, there was little evidence of problem solving—an activity that facilitates students' questioning (Chin, Brown, & Bruce, 2002). The literature reports that questioning is a complex activity which requires teachers to "monitor their own questions, pose questions that intentionally challenge students' intellect and imagination and purposely draw forth students' awareness and employment of thinking skills, cognitive tasks and dispositions" (Costa, 2001, p. 360). There was little evidence that teachers' questioning techniques had been developed at the level of mastery that would facilitate attainment of these higher-order outcomes.

The teachers observed focused primarily on the development of basic process skills. The literature suggests that in spite of exposure to training which encourages the use of hypothetico-deductive reasoning, many teachers retain an empiricist/inductivist view of science based on their

own beliefs about the nature of science (Millar, 2004). This may explain the findings of this study that teachers focused their practical work on the processes of gathering empirical data, and that students were rarely exposed to practical work that required the use of integrated skills such as hypothesizing and experimenting, which develop higher-order thinking.

There was some evidence that teachers, either intuitively or based on prior knowledge and experiences/training, attempted to use strategies that could take their students to higher levels of cognitive engagement. However, both trained and untrained teachers lacked the skills and expertise to effectively use these strategies. On a few occasions, teachers were able to facilitate students' thinking up to Costa's (2001) process level, but facilitation of thinking at the output level was rare. The research evidence points to the important role of the teacher in placing pedagogical emphasis on collaborative group work, effective patterns of classroom talk and interactions, and in eliciting pupils' responses as approaches to developing thinking and making reasoning explicit (Higgins et al., 2004). For the teachers surveyed, the implementation of these principles was either not evident or ineffective.

The untrained teachers did not or could not, as a rule, select strategies that had the potential to definitely promote high levels of thinking. It may be inferred that their practical teacher knowledge was insufficient to facilitate higher-order cognitive engagement in the classroom. While the trained teachers attempted to include some of these strategies, their inability to utilize such strategies effectively is consistent with findings on the behaviours of trained teachers reported in the literature (Beyer, 2001b; Zohar, 2004). The actual teacher behaviours observed in this study were therefore significantly different from the behaviours needed to promote higher-order thinking. The findings therefore indicate the need for a stronger thinking skills pedagogy in the teacher education programme, as discussed below.

When the findings are examined within the Trinidad and Tobago context, there may be two plausible explanations for the behaviours of the trained teachers. Firstly, at the macro level, the model of teacher education that informs the science curriculum process does not focus sufficiently on the eliciting of teachers' prior knowledge within the cultural context in

which teaching occurs. The findings perhaps illustrate the weaknesses of the teacher behaviour development model reported in the literature (Koballa, Jr. & Tippins, 2001). This top-down approach, in which issues related to the development of student thinking (e.g., questioning in the science classroom) are selected by "experts," may not have allowed teachers to reconcile what might be perceived as problematic by experts with their own perceptions about problems that exist in the classroom.

Secondly, the specific micro-level strategies used by teacher educators on the Dip.Ed. programme should be revisited. It is clear that more attention must be paid to specific sub-skills such as: (1) teachers' use of probing questions to have students (a) strengthen and extend their explanations, (b) compare and contrast, and (c) discern patterns and relationships; (2) skills to scaffold students' ideas to extend their understanding; and (3) skills for eliciting students' questions.

The uncovering of the deficiencies noted during the post-training observation of the teachers is significant. It has implications for the type of model used in training programmes to develop teachers' capability to use strategies that could enhance thinking, and for the types of strategies that the science teacher educators use to assist in building teachers' competencies. The success of most interventions aimed at improving thinking is usually based on the evaluation of the outcomes, in terms of pupils' attainment. However, monitoring the effectiveness of the processes used during the implementation, as done in this study, can also provide valuable feedback that may improve outcomes.

After training, it is difficult for teachers to display behaviours that contradict entrenched cultural patterns. Beck and Kosnik (2006) describe individuals who attempt such changes on their own as playing Don Quixote, suggesting that such change "goes nowhere" (p. 41). Over the years, a culture has developed that has socialized many teachers and students into a style of teaching in which teachers adopt the role of transmitters and students function as passive recipients. In addition, teachers who have been socialized into this traditional mode of teaching are often resistant to change (Rudduck & Flutter, 2000), even in the face of curriculum reform initiatives that include goals related to the development of critical and creative thinking.

How then can our science teachers be empowered to provide the kinds of experiences needed to promote the development of competent thinkers? A three-pronged approach is suggested. While this approach is directly applicable the Trinidad and Tobago context, there are lessons for teacher development programmes in general.

Firstly, there is need for a re-examination of the model of teacher development on which the Dip.Ed programme is based. A re-orientation towards the social reconstructivist model (see Beck & Kosnik, 2006) of teacher development is suggested. The teachers and teacher educators should work together to design the course content by reflecting upon teacher behaviours in the science classroom, and on their concerns about levels of thinking promoted. Engaging in reflection would provide opportunities for teachers to deconstruct their prior knowledge, beliefs, and attitudes about teaching thinking, to comprehend how these understandings evolved, and to explore the effects they have on actions and behaviour (Abdal-Haqq, 1998; Zohar, 2004). The reflective process should allow teachers and teacher educators to engage in collaborative inquiry about levels of student thinking, while still keeping the focus on building teacher capacity to address the deficiencies identified. Teachers and tutors could also collaborate to develop complex tasks that demand a high level of cognitive engagement at Costa's (2001) output level. A data base of such tasks could be developed for general use.

Secondly, a thinking skills approach as a direct intervention for building teacher capacity (skills and dispositions) might be included in the programme. The literature suggests that the use of thinking skills approaches as a direct intervention has a positive impact on pupils' attainment (Higgins et al., 2004). Tishman, Jay, and Perkins (1992) also suggest that certain dispositions, such as the tendency to explore, to inquire, to seek clarity, to take intellectual risks, and to think critically and imaginatively, contribute to good thinking. Training that focuses on teaching thinking ought to cultivate these dispositions.

Thirdly, there should be site-based interventions for untrained teachers. Such interventions could draw on approaches used elsewhere, for example, the *Thinking in the Science Classroom* (TSC) project (Zohar, 2004), and also build on some of the positive aspects of the practical knowledge that was apparent in the study. The interventions should be

flexible enough to monitor both processes and outcomes of the training. Such interventions are important because the model of teaching that guides teachers' practice on entry to the service is often based on: (a) experiences as students, (b) knowledge and beliefs about teaching and learning, (c) observation of peers, (d) advice from a senior teacher/mentor, or (e) a combination of these (see Rampersad & Herbert, 2005), and this model does not necessarily promote the development of thinking.

This study provided some insights into levels of thinking into selected science classrooms. It should serve as a springboard for more in-depth research to better understand the cultures in which science teachers operate, and the challenges that they face as they attempt to enact science curricula. Such research should also reveal the kinds of interventions and resources that are necessary to support the development of teachers who can think critically, and who can in turn promote the development of higher-order thinking in the science classroom.

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