MALAWI PRIMARY TEACHER EDUCATION

CRITICAL THINKING SOURCEBOOK FOR

SCIENCE

Malawi Government

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PREFACE

In 2010, the Ministry of Education, Science and Technology (MoEST) and Malawi Institute of Education (MIE) embarked on activities to introduce critical thinking in schools across the country. Both institutions believe that critical thinking skills are essential for sound decision making by learners and citizens alike. In 2013, the *Critical Thinking Sourcebook for Malawi* (CTSM) was published, and it has been used by teachers and teacher educators to develop methods and strategies for the promotion of critical thinking in the classroom. The rationale for the initiative is to improve the quality of education in Malawi.

Through critical thinking, the Ministry of Education, Science and Technology expects that learners will be exposed to survival strategies and skills which will be applied to their daily lives, thereby improving their livelihoods as well as developing Malawi. The MoEST and MIE have taken the next step in the advancement of critical thinking in Malawi through the development of critical thinking sourcebooks in four of the key subject areas in primary schools: humanities, language and literacy, mathematics and sciences.

The sourcebooks share some common sections and chapters, but they also contain subject-specific methods and strategies because critical thinking cannot be promoted in exactly the same way in every subject. In the case of mathematics, for example, learners need to learn how to analyse problems that resemble the real-life purposes to which mathematics can be put and to solve such problems in the most rational way possible. In humanities, learners must develop skills to evaluate claims about healthy living in life skills and environmental conservation. In sciences, learners should be able to analyse natural phenomena and use scientific knowledge, skills, attitudes and values to solve everyday problems.

In languages and literacy classes, it is essential that learners cultivate their creativity through the reading and writing of poems and stories, and develop their ability to analyse information as they improve their listening and speaking skills. Although critical thinking skills can be developed in each of these areas, they are somewhat different by virtue of the subjects themselves. We believe these subject-specific sourcebooks will make an important contribution to the advancement of quality education in the country.

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CHAPTER ONE

Understanding Critical Thinking

Introduction

The term *critical thinking* combines the concepts of clarity and rationality in our reasoning with judgement, discernment and critique in our intellectual endeavors. Although thinking is an activity in which we are engaged during most of our waking hours, *critical thinking* indicates a more active process by which we evaluate knowledge and produce it ourselves. This chapter introduces the meaning and features of critical thinking that will be used throughout the sourcebook. The chapter further discusses the relationship between critical thinking and constructivism as well as the relationship between critical thinking and active learning.

Meaning and features of critical thinking

There are many definitions of critical thinking. For the purposes of the subject-specific sourcebooks, we will use the definition in the Critical Thinking Sourcebook for Malawi (CTSM). It states that critical thinking is "thinking that aims at reaching a well-founded judgment and hence, utilizes appropriate evaluative standards in an attempt to determine the true worth or merit of information" (CTSM,2013; p. 1). In other words, critical thinking is the process by which we make defensible decisions based on thorough evaluation of information to decide upon its trustworthiness and its merit.

This definition suggests several key features of critical thinking that should be kept in mind as teachers and teacher educators. These include:

i. problem identification;
ii. the gathering of sufficient data to form an opinion on a topic;
iii. creative questioning;
iv. reasoned arguments;
v. active consideration of alternative explanations and opinions;
vi. evidence testing;
vii. thoughtful judgment;
viii. development of an independent opinion; and
ix. the sharing of results or opinions in a respectful manner (CTSM, 2013).

Figure 1.1 presents some of the most important features of critical thinking. These features demand different kinds of cognitive skills. Benjamin Bloom, a well-known educational psychologist, helped to develop a taxonomy, or classification scheme, of different domains of learning that included the affective (emotions and feelings), the psychomotor (physical skills) and the cognitive (intellectual skills). The cognitive domain is often the focus of educators; however, affective and psychomotor learning are also important for children and adults alike (Vanderbilt University Center for Teaching, 2016). In recent years, Bloom's original model (Table 1) of the cognitive domain has been expanded to include additional intellectual skills that develop as we move from lower-order to higher-order thinking skills (Table 2).

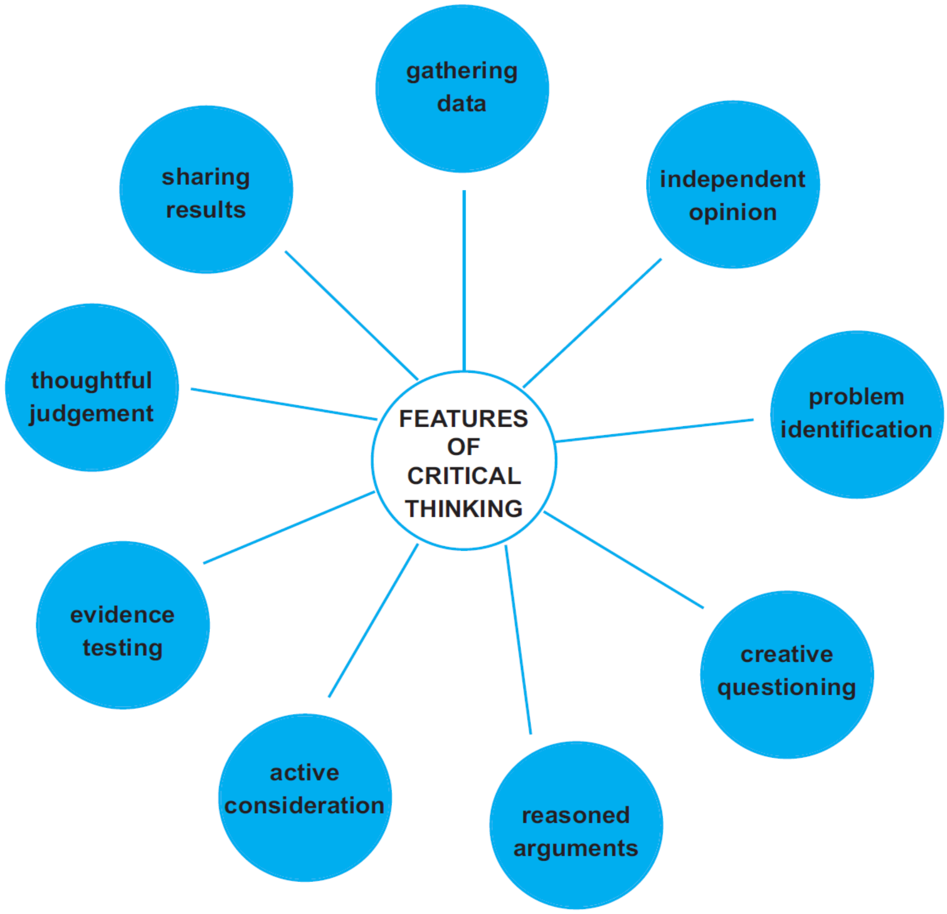

Figure 1.1: Features of critical thinking

Figure 1.1 Some of the most important features of critical thinking.

Table 1: Bloom's original taxonomy of cognitive domains

Lower order thinking skills	⟷				**Higher order thinking skills**
Knowledge	**Comprehension**	**Application**	**Analysis**	**Synthesis**	**Evaluation**
define repeat list recall name relate underline	translate restate explain describe recognise express identify locate report review tell	interpret apply use demonstrate dramatise practice illustrate operate schedule shop sketch	distinguish analyse differentiate appraise calculate experiment test compare contrast criticise inspect question relate solve examine categorise	compose plan propose design formulate arrange assemble collect construct create set up organise manage prepare	judge appraise evaluate rate compare value score select assess estimate measure

Table 2: Bloom's revised taxonomy of cognitive processes: Categories, processes and alternative names

Lower order thinking skills	→	→	→	→	**Higher order thinking skills**
Remember	**Understand**	**Apply**	**Analyse**	**Evaluate**	**Create**
recognizing • identifying **recalling** • retrieving	**interpreting** • clarifying • paraphrasing • representing • translating **exemplifying** • illustrating • instantiating **classifying** • categorizing • subsuming **summarizing** • abstracting • generalising **inferring** • concluding • extrapolating • interpolating • predicting **comparing** • contrasting • mapping • matching **explaining** • constructing models	**executing** • carrying out **implementing** • using	**differentiating** • discriminating • distinguishing • focusing • selecting **organizing** • finding coherence • integrating • outlining • parsing • structuring **attributing** • deconstructing	**checking** • coordinating • detecting • monitoring • testing **critiquing** • judging	**generating** • hypothesizing **planning** • designing **producing** • constructing

Source: *Iowa State University Center for Excellence in Learning and Teaching (2012)*

It is important to note that not all of these levels of the cognitive processes promote critical thinking. For instance, the lower-order skills of remembering, understanding and applying are more basic forms of thinking, while the ability to analyse, evaluate and create are considered central to critical thinking. This sourcebook has a variety of methods and strategies for developing higher-order thinking skills that promote critical thinking.

Benefits of critical thinking

Benefits of critical thinking identified in the CTSM that affect the individual, family/workplace and society as a whole include the following abilities:

- to make complex decisions regarding what to do or believe
- to anticipate the consequences of one's decisions
- to settle disputes by using such attributes as being well-informed, trustful of reason, open-minded, flexible, fair-minded in evaluation, honest in facing personal biases and prudent in making judgments (CTSM, 2013; p. 6).

We can see how these abilities would lead to a fairer and more democratic society by virtue of people's ability to analyse problems, evaluate the consequences of their actions and create solutions that promote equity and justice.

Critical thinking and constructivism

In many countries, educational teaching methods are changing from the traditional teacher-centred approach where knowledge is transmitted to the learners who passively listen and acquire new knowledge, to a constructivist approach where knowledge is constructed or generated by learners. The constructivist approach to teaching and learning entails an active, mental process of development where the learners are actively involved in their learning. Constructivist teaching is based on the belief that learners are the makers of meaning and knowledge. Constructivist teaching fosters critical thinking and creates motivated and independent learners. Therefore, a constructivist teachersees critical thinking at the heart of the teaching and learning process.

A constructivist approach challenges teachers to create environments in which they and their learners are encouraged to think and explore. Young learners learn by resolving cognitive conflicts through experiences, reflection and metacognition (Seaver et al., 2000). For young learners, in particular, direct experiences are vital to the critical thinking process. Teachers present problems that are relevant to the learners and thereafter they give them time to discuss the problem, challenge each other's answers to questions and suggest possible solutions. Such an approach does not develop critical thinking in isolation but as an integral part of the curriculum.

Learning to think critically is a process that takes time and sufficient opportunities to do so.

The constructivist teacher must give learners opportunities to explore ideas, to question and to take risks is to create a rich environment for critical thinking. It is evident when observing children that even those aged five to seven are capable of thinking critically. Not only do they talk about their thinking, but they also demonstrate emergent reasoning skills. By the time children reach the upper grades in primary school, they should be comfortable and capable in using cognitive skills from lower- to higher-order thinking.

Critical thinking and active learning

Constructivism is based on the premise that teaching and learning are active processes in which existing knowledge is analysed and evaluated, and new knowledge is created through interactions between teacher and learners in the classroom. Thus, we can think of active learning as informed by constructivism and as central to the critical thinking process. According to the CTSM, active learning "encourages learners to make sense of information by engaging in the learning process through participation in a structured learning activity to obtain desired learning outcomes" (CTSM, 2013; p. 35). One of the key words in this definition is *participation.* Participation can also include active methods that simultaneously promote psychomotor development, such as role playing and experiments. There are many ways to promote active learning, and the chapters in this sourcebook will provide suitable examples for specific subject areas.

The principles of active learning are closely linked with the broader principles of critical thinking. Five of the most important linkages are:

i. Meaning-making occurs when learners link their existing knowledge and new knowledge.
ii. Learning by doing is more powerful than only learning facts.
iii. Learning includes transferring knowledge from one domain to another.
iv. Learning involves the co-construction of meaning through interactions with others.
v. Speaking and writing are important ways for learners to articulate their understanding. (CTSM, 2013; p. 36)

These linkages apply to all learning areas or subjects, and we demonstrate how to make these linkages visible in Chapter 5, where we suggest ways to promote critical thinking across the curriculum.

Conclusion

This chapter has laid out the rationale for its use in Malawian schools. It has also introduced the concept of critical thinking. It has gone further to explain the relationship of critical thinking to cognitive domains and higher-order thinking skills, constructivism and active learning. The next chapter will discuss in greater detail on how to teach for critical thinking and characteristics of critical thinkers in the subject of science.

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CHAPTER TWO

Becoming a Critical Thinker in the Teaching of Science

Introduction

Becoming a critical thinker is a conscious process that involves extensive and comprehensive practice. One approach to promoting critical thinking is to incorporate it into the school curriculum. The final goal of this process is to become a person with reasonable judgment in problem solving and in life in general so that critical thinking becomes a routine. Critical thinking in sciences uses scientific skills, values, attitudes and experiences in order to make meaning of the scientific phenomena and generate and apply scientific knowledge.

Learning science subjects is a good way of acquiring critical thinking skills. Scientific thinking, including its concepts, principles and methods, is a powerful way to obtain relevant and reliable knowledge about nature. Sir Peter Medawar, a scientist who won a Nobel Prize in 1960, stated, “In terms of fulfillment of declared intentions, science is incomparably the most successful enterprise human beings have ever engaged upon” (Schafersman 1991, p. 5). Being a good scientist implies that one is practicing critical thinking, although anyone can “think like a scientist.” Thinking like a scientist includes being open to new evidence that disconfirms one’s ideas, reasoning dispassionately, demanding that claims be backed by evidence, deducting or inferring conclusions from available facts and solving problems (Willingham, 2007). This is the kind of thinking that we should encourage learners and teachers to practice in everyday life, including but not limited to science classes and laboratories.

This chapter explores the characteristics of a critical thinker in science and the stages a person passes through to become a cultivated critical thinker. It will also discuss how teachers can help learns to progress toward becoming science-oriented critical thinkers.

Characteristics of a cultivated critical thinker

We are not all critical thinkers at this moment, but we are all capable of developing critical thinking skills in environments that promote them. In the sciences, critical thinking and scientific inquiry are inseparable. Both demand that learners examine natural phenomena and propose questions about them, develop hypotheses to explain them and use data effectively in drawing conclusions and proposing solutions.

The following are some of the most important characteristics of a critical thinker in science:

(a) *Identifies problems and raises vital questions by formulating them clearly and precisely to determine what, why, when and how things happen.* Questions such as the following might be asked by primary school learners:

- What makes sandwiches go bad when they are left in a school bag for a long time?

- Why does the colour of universal indicator paper change when exposed to various substances like lemon juice, ammonia, cleaning products, tap water, pure water, soft drinks?
- What are the best weather conditions for kite flying and why?

Critical thinkers in science are keen to solve problems. They can identify the existing scientific literature on a problem and the resources and skills needed to solve the problem and reflect on the problems they have solved before. They ask themselves what solutions could work, and work best, in this new situation, and how to test if a solution would work. Thinking about and then attempting to solve problems, especially real-life problems, develops critical thinking. Consider the example below:

Example 2.1
When preparing tea, why is hot water preferred to cold water? (adapted from MIE, 2008)

A critical thinker, when trying to find out a solution to this problem, will ask themselves questions such as: "Why should we use hot water?" "What happens to tea in hot water that does not 'happen' in cold water?" "What does heat do to water particles?" "How do water particles behave when heated?" "What is the effect of hot water particles on tea leaves?" "Are there other options that could explain this phenomena?"

(b) *Gathers and assesses relevant information using abstract ideas to interpret problems (or situations) effectively*. When doing so, critical thinkers apply existing scientific knowledge, values, skills and attitudes to effectively find an explanation or solution to the given problem. Thus, critical thinkers:

i. Decide how to approach a problem for which they have no immediate explanation. Critical thinkers may consult existing scientific literature and carry out an investigation for a solution to the problem.
ii. Choose the most appropriate way to represent a scientific situation. They may wish to represent their observations in graphical, tabular and prose (paragraph) formats.
iii. Monitor the experimentation progress and adjust it as necessary. They will make appropriate observations and control variables at necessary stages of an experiment or investigation.
iv. Analyse their observations or results and ask, "Does this make sense?" Before making a statement as an explanation or solution to a given problem. Critical thinkers will consider other explanations that might explain the outcomes they have observed.
v. Communicate their scientific ideas effectively to others. Before carrying out an observation or experiment, critical thinkers will have the aim clearly stated regarding what is being investigated and will formulate likely hypotheses.
vi. Connect their scientific ideas, concepts and methods (processes) with their own lives and their wider world. (The Critical Thinking Consortium, 2013). After finding the solution to a given problem, critical thinkers will start to think about other applications for their findings. They will realize that the science learnt at school is, in fact, applicable to everyday life.

These six points illustrate how a critical thinker would gather and assess information to seek solutions to a given problem.

(c) *Proposes a solution or answer to the problem under investigation*. These proposals are called hypotheses, or educated guesses, and they must be testable. (Schafersman, 1997; p. 9) explains, "A scientific hypothesis is an informed, testable and predictive solution to a scientific problem that explains a natural phenomenon, process, or event." If the prediction, which a critical thinker makes is not testable, then it cannot be examined scientifically to determine its viability. In Example 2.1 above, if a learner predicts tea leaves themselves are part of the solution, they will not be thinking critically because the same tea leaves put in cold water will not 'behave' in the same way when put in hot water. Thinking in terms of tea leaves as the causal agent is not a good prediction or hypothesis because the leaves are a constant factor while water temperature is a variable factor. Therefore, water temperature must be central to the difference in the 'behaviour' of the tea leaves. This example also reminds us that critical thinkers should be able to make connections between abstract ideas learned in school and strategies to solve problems of everyday life, such as the essential steps in the making of a cup of tea.

(d) *Tests a hypothesis before it is verified and validated*. The most common way of testing hypotheses is by conducting an experiment, e.g., placing tea leaves in cold water and in hot water and observing changes in water colour. The second way of testing predictions is to make repeated observations by conducting the same experiment multiple times or making comparisons of natural phenomena. An example of this latter case might include comparing the sedimentation of several mountains to understand common aspects of their formation. It is important to emphasise to learners that only hypotheses involving natural processes, natural events and natural laws can be tested. Supernatural events cannot be tested, and therefore any prediction in this realm will imply that learners are not thinking critically.

(e) *Knows when to accept or reject an initial hypothesis*. When rejecting, critical thinkers should be able to determine whether to modify their prediction or abandon it completely. If they choose to modify it, then retesting it is necessary. In addition, critical thinkers need to think beyond the norm or the known by showing they are able to construct, support or challenge an existing scientific theory. Examples of scientific theories include the theories of relativity, quantum mechanics, evolution, genetics, etc. Although these are very well-established theories, critical thinkers should be open-minded when it comes to considering alternative systems of thought and alternative theories. They should also recognise and assess their own assumptions, the implications of these assumptions and their practical consequences.

(f) *Knows how to communicate findings effectively*. Science communication can be defined as any activity that involves a person transmitting information to others based on research and receiving feedback from another person about it. This is usually done in the form of presentations, papers in journals or books, or in the classroom with the goal of educating others about the experiments or observations one has done (Felieu-Mojer, 2015). Therefore, critical thinkers in science must learn how to communicate effectively using each of these formats. This begins with learners in the classroom or science laboratory asking compelling questions like: "So what?" "Why does this matter?" "How did these results come about?" "What should I do next and why?" Effective communication also means learning to accept any shortcomings in their work and value reasonable ideas from others. Consider the example below:

Example 2.2
John planted 3 bean seeds in a tin. After 10 days he observed that the seeds did not germinate. What could be the possible reason?

Learners who have good critical thinking and communication skills will have formulated a hypothesis about the seeds before planting them and shared this hypothesis with the teacher and other learners (or will have written a research proposal if in senior primary). The learners will then conduct the observation and record their findings. The final stage in the process will involve sharing with the class their conclusion as to why the seeds did not germinate. For instance, the learners may explain in oral or written form that not all of the conditions necessary for seed germination were present, and the critical thinking science learners will be able to listen to reasonable explanations and recommendations for future experiments from others.

Scientific literacy is closely related to critical thinking. Currently, many schools and teachers' colleges are introducing scientific literacy. According to NCSESA, a scientifically-literate person "can ask, find, or determine answers to questions derived from curiosity about everyday experiences." Moreover, they "can identify scientific issues underlying national and local decisions and express positions that are scientifically and technologically informed" (NCSEA, 1996; p. 22).

Specific characteristics of science teachers who think critically
Science teachers who are critical thinkers teach their learners "how to think" and not just "what to think" (Clement & Lochhead, 1980). *What to think* refers to content, and *how to think* means a scientific way to understand and evaluate this content. Science teachers must pass on critical thinking skills, attitudes and values to their learners so that the content 'delivered' in the classroom is comprehended and retained. Yet this is not sufficient for science teachers who think critically. They must also create a conducive classroom environment to enhance critical thinking so that learners learn how to think about content presented by teachers and content they encounter on their own in everyday life. In this way, according to Schafersman (1991), learners are able to think for themselves and will be able to identify problems, gather relevant information, analyse information in a scientific way and come to informed conclusion by themselves. Therefore, the following are characteristics of a science teacher who thinks critically:

i. They utilize a variety of questions, mainly open-ended questions that can be answered using multiple approaches, with the aim of encouraging learners to think before responding. They also use higher-order questions based on Bloom's taxonomy, as discussed in the previous chapter, to promote analysis, evaluation, synthesis and creating new knowledge. Effective, higher-order questioning builds learners' critical thinking skills and hence promotes the kind of creative thinking essential for science.

Examples of questions that a science teacher who thinks critically might ask include: "What if?" "Why?" and "How?" Tasks that promote higher-order thinking include terms like: "discuss," "explain," "analyse" and "evaluate." These kinds of questions and terms are quite different from those that only allow for lower-order thinking, as in "What is?" and "list", "mention" or "label."

ii. They know the subject matter to the level above the level being taught (Ball & Forzani, 2011; Kessel, 2009). Knowing the content well has a significant effect on what a learner can learn and hence on learners' thinking. For example, knowing the content well can help teachers to choose the most suitable questions to ask, the best examples and resources to use in class, and examples and questions that promote higher-order scientific thinking.

   Content knowledge also helps in understanding and detecting errors and misconceptions in learners' work, allowing teachers to provide prompt feedback. Willingham asserts: "The ability to think critically depends on having adequate content knowledge; you can't think critically about topics you know little about or solve problems that you don't know well enough to recognize and execute the type of solutions they call for" (Willingham, 2007; p. 12).

iii. They create active learning environment that helps learners to develop a repertoire of thinking tools they can use confidently and independently. That is, a science teacher who is a critical thinker will entertain probing questions from learners and provide necessary platforms for their learners to explore and verify scientific facts and concepts. Not only does the learning environment demand that teachers respect learners' reasonable views and opinions, but also requires fellow learners to respect each other's opinions.

iv. Critical thinking science teachers facilitate learners' ability to reach well-reasoned conclusions and solutions, and to express their views in spoken and written forms. They help learners to prepare research/project proposals, carry out these projects, and communicate/report the observed results and conclusions drawn to the class or wider community. Thus, critical thinking learners will appreciate that there are multiple ways of approaching scientific problems, and they will be able to identify SMART (Specific, Measurable, Achievable, Relevant and Timely) and efficient approaches (Blanchard, Zigarmi, & Zigarmi, 1985). These teachers also allow the use of varied presentations, i.e., in prose, tabular and graphical formats, for solutions as a means of encouraging different ways of communicating with others.

v. They create lessons and activities for use in the classroom or other settings for the teaching of sciences to encourage learners to reason within alternative systems of thought. This is important because it helps learners to recognize and assess their assumptions and the implications and practical consequences of their work. Critical thinking science teachers also provide clear, explicit and timely feedback to learners, which aims at improving learners' learning rather than only evaluating their work.

vi. They guide learners to communicate effectively with others in their spoken and written work. Critical thinking science teachers will provide their learners with material and non-material resources for them to seek solutions to complex problems. Therefore, they guide their learners in how to interact with others in their family, school/workplace and in their community.

vii. They propose multiple ways of addressing a particular problem, leading to different, yet justifiable, outcomes. Common problem-solving strategies in science include: creating visual images, e.g., graphs and pictures; creating tables; using manipulatives; working backwards; looking for patterns; and conducting experiments.

Drawing learners toward critical thinking when teaching science

Critical thinking can be incorporated directly in the teaching of science because it enhances scientific reasoning. To cultivate critical thinkers in sciences, teachers should consider the following seven practices:

1. *Determine and share with learners the learning objectives for each of the critical skills in science based on Bloom's taxonomy, including problem solving, application, analysis, synthesis and evaluation*. Teachers should identify key competencies to be learnt and write them in a language that learners will understand. They should use action verbs to list specific learning outcomes. Teachers could use the following verbs in describing what learners should be able to do:

    - ***Design*** *an experiment*
    - ***Carry out*** *an experiment*
    - ***Record*** *observations*
    - ***Interpret*** *results*
    - ***Draw*** *conclusions*
    - ***Communicate*** *results*

    Additionally, science teachers who think critically should consider sharing success criteria with learners so they can be aware of the scope of the content and assess their own learning. They should also set clear expectations for meaningful participation in pair/group work and allow learners to ask for clarification when needed.

2. *Choose instructional activities that provide opportunities for learners to engage in critical thinking*. Inquiry-based learning activities are particularly engaging in science as learners learn skills to interpret, synthesise and evaluate information. Inquiry-based learning also increases motivation and engagement through the process of finding solutions to problems. Therefore, learning activities should be centred around inquiry-based learning.

3. *Model the way they think when solving problems to help learners strengthen their own ability to articulate their thinking process*. This modeling can be part of scaffolding strategies that guide learners through the problem-solving process. Modeling thinking can also encourage learners to persevere during problem solving. It may

also be helpful for teachers to model scientific thinking from the learners' perspectives – as if the teacher is tackling the problems for the first time.

For instance, consider **Example 2.1** above. Science teachers who think critically will together with the students design an experiment, carry it out and draw conclusions from the data collected with their learners. This is in contrast to teachers who 'deliver' the knowledge to their learners that water particles, when heated, gain kinetic energy and move faster, thereby dissolving tea leaves more easily and faster than when the particles are cold.

4. *Teach through questioning to develop the critical thinking skills and include convergent (Bloom's lower-order thinking) and divergent (Bloom's higher-order thinking) questions*. Divergent questions are open-ended and, therefore, can often be answered using multiple approaches and may result in multiple answers. These questions help learners to choose the SMART techniques in solving problems since there are different alternatives and, hence, they promote critical thinking.

   It is important to ask the best questions which can promote learners' critical thinking skills. These include questions that demand learners to evaluate the clarity and accuracy of their thinking (Peter, 2012). Teachers should choose questions carefully before each lesson, matching them with the learning outcomes and encouraging scientific 'talk' in the class. Some useful questions to use in class that support learners' critical thinking are listed in Peter (2012, p. 41). They include:

   - What do you think about this?
   - Why do you think that?
   - What is your knowledge based upon?
   - What does it imply and presuppose?
   - How are you viewing it?
   - Should it be viewed differently?

5. *Review, refine and improve lessons by monitoring learner engagement in activities in classrooms and in laboratories, and collecting feedback from learners*. One way to do this is to let learners defend their solutions – why do they think they have arrived at the correct answer or correct conclusion? Why do they believe their experimental method is the most efficient of all the methods that have been learned or discovered? In the case of multiple approaches, critical thinking teachers should let them choose which approach might be the best and provide time for learners to discuss and solve problems in pairs or groups. Teachers should strive to create an active learning environment with very high expectations and provide room for learners to reflect on their actions through involvement in learning activities. For example, teachers can model and encourage learners to ask themselves questions like, "Where will I use this kind scientific approach in my life?"

6. *Provide prompt feedback to learners that is both motivational and descriptive rather than solely evaluative*. It is important for teachers to let learners know where they have done well and where they need to either improve or move to higher-level of thinking, and how to do so. For example, a comment like the following provides feedback on what the learner has done well and how the learner can move to a more

advanced level: "Well done. You have planned a meal based on the three food groups, now consider the recent six food groups in your meal planning."

Teachers should also provide assessment frequently to improve learners' scientific skills and create opportunities for self-assessment. Teachers also need to make sure there is a connection between learning outcomes, success criteria, teaching methods and assessment. Creating rubrics to help learners focus on the most important parts of a lesson or unit and making assessment practice transparent can help learners set their own learning goals and can support them in reaching their target.

7. *Reflect after each lesson, whether it is in class or in the laboratory.* Whenever possible, teachers should create a reflective journal to document events in the classroom and laboratory, and actions that might be taken to improve both teaching and learning in these spaces. This journal can be very helpful for future reference when teaching the same topic, and it can help to improve current learners' critical thinking in science by modifying the next lesson to encourage even more higher-order thinking (Duron, Limbach, & Waugh, 2006).

Conclusion

In this chapter, we have seen that there is a difference between knowing about scientific concepts and scientific theories, and knowing how to think about and do scientific research. Critical thinking in the teaching and learning of science includes knowing how and why natural phenomena occur, how scientific laws and principles have been generated, and how to use them to predict future occurrences and apply this knowledge in everyday life. The chapter has also shown how teachers of science can promote active learning by engaging learners in inquiry-based and collaborative activities. They can use questions that promote higher-order thinking and model the thinking process to help learners think for themselves in a way that they can identify problems, gather relevant information, analyse information in a proper way and deduce reliable conclusions. In this way, learners become responsible and productive members of their communities. The next chapter discusses specific methods and strategies for science teachers to use in order to support learners develop critical thinking skills.

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CHAPTER THREE

Specific Critical Thinking Methods and Strategies for the Teaching of Science

Introduction

Critical thinking is similar to scientific thinking as they are both learned skills that require instructions and practice (Schafersman, 1991). For this reason, critical thinking is easily integrated into the teaching and learning of science as a school subject. Methods and strategies of incorporating critical thinking into science are designed to focus on critical thinking skills, which include inferences, analysis, interpretation, synthesis, evaluation, exploration and self-regulation.

This chapter will discuss critical thinking methods and strategies for the teaching of science. It will focus on general and specific instructional strategies in the teaching of science with the following features:

- Create content learning momentum and invite varied responses from learners;
- Allow for learner thinking time and reflection on the critical challenges they face in the classroom (or laboratory) before producing a response, followed by time to reflect on their responses and make revisions; and
- Promote collegial interactions involving a learner and a teacher, and learners and peers.

The overarching goal of the chapter is to provide examples of how to use critical thinking strategies that engage learners in the analysis and creation of science-based knowledge as appropriate for primary school classrooms and laboratories.

Factors to consider when using critical thinking methods and strategies

General considerations

There are a number of general considerations for science teachers who seek to promote critical thinking. Some of the most important are discussed below:

(a) *Use meaningful learning outcomes and share them with learners*. When learners understand the learning outcomes, it helps them to be focused in their thinking. Teachers should use action verbs to define learning outcomes and present them to learners at the beginning of a unit or lesson. For example, learners could be given the following overarching learning outcome before a lesson on the importance of liquids and healthy beverages for human beings: *to appreciate* the importance of liquids and healthful beverages in one's diet. Specific learning outcomes (or success criteria) could be written in a similar manner: *to describe* different kinds of beverages; *to prepare* nutritious beverages; *to distinguish* healthful and unhealthful beverages; and *discuss* the value(s)of beverages in our diet.

(b) *Match teaching methods and strategies with the characteristics of learners, e.g., weak learners, able learners or mixed ability*. For example, a lesson on rocks and soils could be developed so that learners work individually, in pairs and in small groups with more time spent using one arrangement rather than the others based on the characteristics of the learners. For example, if a particular class has several weak learners, the teacher could form mixed ability groups with these learners given more responsibility for collecting rock and soil samples based on certain criteria, and learners who are considered more able could lead the group in examining and analysing the samples. It is a good idea for teachers to plan in advance how the groups will be organised and to give weaker learners more opportunities for leadership as the school year progresses and their learning develops.

(c) *Adapt learning activities and materials to accommodate those who have learning difficulties*. One way to address learning difficulties and differences is to draw on learners' experiences when introducing a concept, especially for learners with less content knowledge. For the beverage lesson described in (a), the teacher might start by asking learners with learning difficulties some basic, lower-order thinking questions such as, "What are some beverages you and your family drink at home?" Stronger learners could be asked higher-order questions such as, "What are the dangers of taking too much alcohol?"

(d) *Match class activities with particular school and community norms so that the activity does not violate rules about appropriate questioning*. For example, in this beverages lesson, it not appropriate for learners to prepare a beverage like *thobwa* that can be fermented and then turns to beer. Instead, learners can discuss the process of fermentation, analyse some of the problems associated with excessive alcoholic beverage consumption, and make, instead, a series of juices with locally-available fruits.

(e) *Match learning activities with the materials, space and size of the class*. If teachers have large classes, they can conduct some activities outside the classroom, depending on the school setting. For instance, a large class of learners could be divided into small groups to collect rocks and soil samples on the school grounds. They could show their findings to the rest of the class at different designated spots, preferably in the shade, on the grounds. If it is not common to take learners outside, teachers should be sure to inform the school administration before doing so and explain the pedagogical purpose for the activity. Teachers should also check in advance that there will be enough space before the start of any activity and enough supplies and other resources for each learner or small group of learners to use.

(f) *Show that knowledge is not static*. Teachers should build into their lessons opportunities for learners to explore different methods of obtaining solutions for their current problem and to decide which one is best based on evidence obtained. For example, in the study of beverages, learners could explore different ways of improving the colour, texture, flavour, consistency and taste of different juices based on how thoroughly the fruits are processed and how much boiled water is added to them. They could then write a short report for future classes to help them utilize the suggested improvements in juice preparation to show learners there is always a room to improve existing scientific principles depending on specific scientific problems identified (CTSM, 2013).

Specific considerations for science classrooms
There are also specific considerations that science teachers should keep in mind as they prepare lessons designed to teach content and critical thinking:

- *Consider the practical insights and real-world utility for science that learners can take away from each lesson*. Teachers should relate each science lesson to some kind of real-life application, even in simple problem-solving procedures where one asks these questions: What is the problem in front of me? What information do I have about this problem? Which strategies/approaches will I use to solve the problem? Which approach is faster and cheaper? Have I solved the problem? Could there be another solution? These questions will help learners to approach practical, real-life problems with care and thoughtfulness – and in so doing they will apply critical thinking to these situations.

- *Pay particular attention to the level of science comprehension, age and gender of learners in choosing methods that will encourage and not inhibit their active classroom participation*. It is especially important that teachers ask questions in a manner that encourages the participation of every learner in class, provides thinking time and avoid too many chorus (whole class) answers. This requires that teachers use gender-responsive pedagogy, which means choosing activities and examples that promote critical thinking for both boys and girls and that avoid stereotypical examples that imply science and science-related jobs like medicine are only for men.

- *Think creatively about how to use locally-available resources to create teaching and learning resources*. In addition to the beverage and rocks/soils examples above, many science lessons can use resources found in the community. These include seeds that can be planted and observed in a unit on growing plants; scrap metal and bottle caps that can be used to make small cars (*galimoto*) for a unit on friction; and a torch with batteries for teaching about light and shadows. Experience has shown that many learners believe the only jobs for people who like science are those at colleges and universities. Thus, for those learners who like science but not teaching, they might not see the need to engage in science lessons because they believe it is not for them. Thus, teachers can use local experts as important resources who can come to the classroom and link the science taught in school to their professions and to the community service. Some relevant local experts include laboratory technicians, nurses, and doctors; food scientists who work at beverage bottling plants; and agronomists (soil scientists) who work with farmers.

- *Find ways to show learners that science does not operate in a vacuum by bringing in examples where science has been applied locally and internationally*. The following are some examples to show that science can be applied in many contexts:

  i. Improving the yield in gardens and farms during a unit when learners are growing their own plants at school;

ii. Effects of bacteria on food during a lesson in which learners observe moldy fruit and bread and discuss the implications for long-term food preservation to prevent hunger in Malawi; and

iii. Importance of oxygen for human life when learners are studying the challenges of living on the moon or other planets.

Critical thinking methods for teaching science

In this section, a variety of methods designed to enhance critical thinking are discussed. As noted above, this is not an exhaustive list but one that can guide science teachers' decision-making about appropriate methods for different kinds of topics and at different points in a unit of study. The methods below were chosen using the knowledge that critical thinking is an active process aiming at enhancing the application of life skills, particularly those described in CTSM (2013; p.5).

Exposition methods

Exposition methods aim at introducing new information and develop new learning by connecting it to prior knowledge. In science, new learning is developed using learners' real-life experiences with the natural phenomena around them. A science lesson should start with clear goals so that learners understand what they are expected to learn, and it should make explicit how this is connected to what learners already know about some aspect of the topic. The importance of connecting new ideas and concepts to what learners are expected to learn in a lesson has been emphasised by many educational researchers. In particular, research has found that using learners' experiences to introduce new ideas and concepts is especially important for weaker learners (Sullivan, 2011). Thus, exposition methods can be quite valuable, especially for learners in the primary school years.

Structured overview

A structured overview is a summary of a topic that highlights key concepts and is meant to arouse a learner's curiosity. Usually given at the beginning of a lesson, a structured overview comes in the form of a lecture and is particularly useful when learner's previous knowledge on the topic is minimal. This method is useful in promoting critical thinking in science because it affords learners the opportunity to link concepts and information in constructing new knowledge. The following are examples of curriculum areas suited for structured overview for a unit on the earth:

Table 3.1: Earth Science

Topic	**Suggested Overview**
Fossils	Definitions of terms like "geology" and "evolution" (adapted for the age of the learners)
Continents	Different ways of distinguishing continents
Earthquakes	Map showing location of recent earthquakes and major fault lines around the world

K-W-L
These letters stand for Know, Want to know, and Learn. It is an exposition method suitable for the first day of a new topic because it directly connects learners' prior knowledge with new learning. Teachers can use this method during one lesson or across several lessons.

Steps in K-W-L

a. The teacher introduces a topic and asks learners to write down in the **K** column on a piece of paper or on the blackboard anything they already know about the topic.
b. The teacher asks learners what else they want to know about the topic, and the learners or the teacher writes this down in the **W** column.
c. Teacher facilitates a lesson or several lessons on the topic, factoring in what the learners want to know.
d. The teacher asks the learners to acknowledge what they have learnt at the end of the lesson or unit on the topic, and the learners or the teacher records this in the **L** column of the K-W-L chart.

The K-W-L method is useful in developing critical thinking for two reasons. First, learners are kept active as they think about what they know and ask questions about what they do not know. Additionally, the method encourages learner reflection to verify whether they have learned what they acknowledged they did not know at the beginning of the lesson or unit.

The following are a couple of examples of science topics suited for K-W-L:

- What do you *already know* about how you can keep your teeth healthy? What more do you *want to know* about how to have strong, healthy teeth? (first day of a lesson on teeth) What *did you learn* during the lesson/unit about keeping your teeth healthy?

- What do you *already know* about the sun? What additional information do you *want to know* about the sun? (first day of a lesson on the sun) What *did you learn* about the sun that you did not know before our lesson?

Instructional Note-Taking System for Enhanced Reading and Thinking (INSERT)
INSERT is a teaching strategy that provides a system of simple symbols which are used by learners to note their responses and help them construct personal meaning from the text. It is mainly used at the building knowledge phase of a lesson. INSERT develops learners' investigative, interpretive and evaluation skills; hence, it can be a good tool to promote critical thinking in science classes when learners are reading about a topic. It could be employed anytime during a lesson, but it is particularly useful as homework because learners will have enough time to read, process and make the needed markings. Teachers could even use it prior to a scheduled lesson in order to assess learners' difficulties coming into the lesson.

INSERT uses four different marks. These are:

√ a checkmark, signaling that what learners are reading confirms what they knew or thought they knew.

- minus, signaling that what learners are reading contradicts or is different from what they already knew or thought they knew.
- \+ a plus, signaling that the piece of information a learner encounters is new
- ? a question mark, signaling that information is confusing to the learner or that there is something the learner would like to know more about. (CTSM, 2013)

For example, learners in senior primary could be given a reading passage about *evolution*. They would mark with a √ the statements that confirm their understanding of the concept of evolution and evolutionary theory. They would mark with a minus any information that contradicts their understanding, and this may be the case for learners whose religious views are not consistent with evolutionary theory. The learners would mark with a + any new information that is not contradictory or different from their prior knowledge and would use a ? to indicate where they would like additional information about something or where they need clarification.

Co-operative learning methods

These are some of the most powerful and most common methods of teaching and learning

Science because scientists tend to work in teams and build on the knowledge of earlier researchers. Learners in groups (assigned by their teachers or by themselves) work together to solve problems with the intention of learning from each other, thereby enhancing learners' social development. Learners typically enjoy working in groups to complete a variety of activities rather than sitting down and listening to the teacher for the entire lesson.

Brainstorming

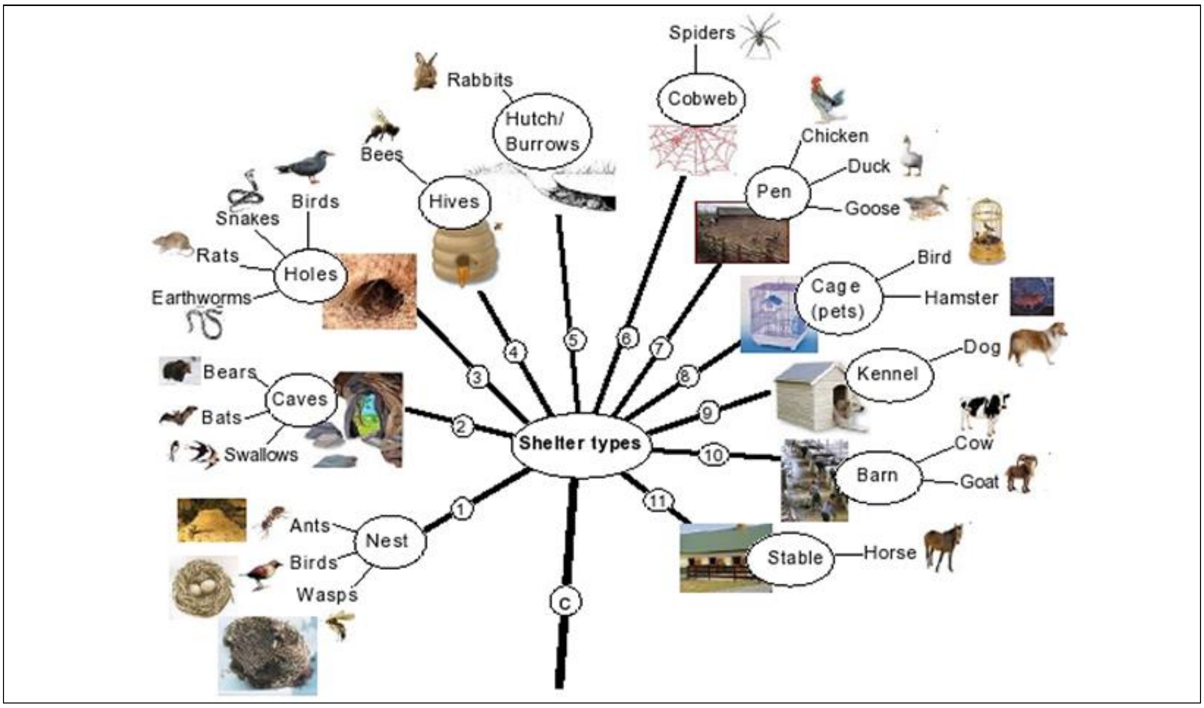
Brainstorming is a method in which learners think about and suggest ideas on a given topic. It is used primarily as a starter or at some point during the main lesson when the teacher wants learners to bring in new ideas about a concept or to discuss the best strategy of solving a problem. Encouraging a pool of ideas to flow in a classroom requires the participation of the majority of learners, hence the need to make learners feel free to open up and give their own ideas. An important feature of brainstorming is that there is no single correct answer and so no excuse for non-participation. As ideas are shared with others, learners go through a process of refinement with others, building on, deducting from and reformulating their ideas to make them more robust.

Some examples of brainstorming questions for different topics in the science curriculum include the following:

- What kinds of exercise could we do at school to improve our health?
- How could we conserve electricity in our country?
- What kinds of foods should we eat each day to keep our bones and teeth strong?

Mind mapping

This is another way to do a brainstorming activity by organising the ideas that learners generate while brainstorming to show relationships between these ideas. It can also be used to gather information on a concept or to solve a problem by starting with the main theme and then breaking it into branches as desirable. The following is an example of a mind map based on learners' brainstorming about types of shelters:



Source: http://sciencemindmaps.com/

Inquiry based learning (IBL)

This method starts with a question, and learners use this question to construct their own knowledge. IBL is based on the view that learners will be more involved in learning and will use higher-order thinking skills like analysis, synthesis and evaluation when they are doing their own investigation. The figure below shows the diagram for any IBL procedure (Crombie, 2015):

There are three levels of IBL in most science lessons:

- *Structured*: The teacher directs the inquiry by providing the question and step-by-step instruction on how to inquire.
- *Guided*: The teacher provides the question, and learners take responsibility for the investigation, presentation, discussion and reflection.
- *Open*: Learners take responsibility for establishing the question and the inquiry while the teacher only provides support.

Any of these three levels could be used effectively to promote critical thinking so long as ample opportunity for higher-order thinking is built into the lesson. IBL can be particularly useful for topics addressing the earth, weather, energy or the environment because learners can easily investigate questions in these areas in their community. Examples of initial questions that could be posed to learners to begin the IBL process are as follows:

- *Would you recommend to your friends that they go fishing in [name of stream or river near the school]?* Learners could then examine any sources of pollution in the water source and analyse how they might affect the health of fish, and the health of the friends who might eat it. They would then present their report, discuss the pros and cons of fishing in this water source and reflect on what they as a class could do to improve water quality

(Source: https://www.edutopia.org/practice/inquiry-based-learning-science-classroom)

- *How is nutrition linked to health and development?* (MIE, 2008, Unit 10). The activities outlined in this unit provide a baseline for planning structured or guided levels of IBL to lead learners into researching the relationship between nutrition, health and development.

Self-expression methods

Self-expression methods provide learners with an opportunity to communicate, with fairness and integrity, how they think and feel without being accusatory, judgmental or abusive (see CTSM, 2013). These are particularly important in science classes because learners may have different views about some issues, such as the causes of climate change or evolution.

Debate

Debate is popular method of teaching in which learners defend their position on a two-sided issue about which there are strong opinions. Questions that elicit a yes or no response are best suited for debates. To start a debate, the teacher poses a question, and learners take—or are assigned to take—one of the two sides and develop arguments to support their position. To develop critical thinking skills using the debate method, it must be organised well and done effectively.

While there are different types of debate, all of them follow a common format:

1. There is a resolution of policy or a value that provides the basic substance of the discussion. The terms of this resolution will be defined by the first speaker of the debate, or by the teacher.
2. There are two teams representing those in favour of the resolution and those against it.
3. The affirmative speaker always has the burden to prove his/her side.
4. The debate closes with final rebuttals on both sides which summarizes their respective positions (Speech and Debate Union, 2004).

Some resolutions that might be used for a debate in science, particularly in senior primary, include the following:

- Intelligent animals like chimpanzees should not be used for scientific research.
- Coal mining should be banned in Malawi because of its impact on global warming.
- Wealthy countries should cease space exploration and use the money instead to address environmental problems for which they are primarily responsible.

Value line

Besides debates, issues to which there is a varied degree of agreement and disagreement can employ the value line method. When issues for which opinions vary come up in class, teachers can ask learners to take positions on an imaginary line between two extreme positions. Learners with two opposing positions take their place at the two extreme points (e.g., two corners of the classroom). The imaginary line between them is filled by learners based on the side of the issue to which they closely associate. Learners take turns to justify their positions and advance reasons for their stance.

Steps in the value line method

a. Teacher poses a question with a yes/no answer options.
b. Learners consider the question and make a choice of answer with a supportive reason. In some situations, learners could write down their reasons.
c. Two learners with extremely contrasting positions stand at opposing ends of the classroom with an imaginary line between them.
d. Other learners are invited to take positions on the imaginary line depending on which side of the argument they support.
e. Learners are invited to share reasons for positions on the continuum.
f. Unlike debates, learners are allowed to change positions upon hearing others defend the choice of their position.

The power of the value line in promoting critical thinking is the ability it affords learners to experience a demonstration of their thoughts within a physical space. Value line can also help in the development of critical thinking because learners justifying their positions are required to use analytical, interpretation and explanation skills. Its additional value of making people work together also promotes learners' social skills. Learners' ability to change their minds and relocate on the continuum helps in their analytic skill development.

Using the examples above under *Debate*, a teacher could reformulate them as yes/no questions for a value line:

- Can animals be considered intelligent beings?
- Should coal mining continue in Malawi?
- Are space programs a good use of money?

Reflective methods

Reflective methods help learners to link theory, practice and experience. In doing so, they are able to understand the relevance of learning and evaluate their strengths, weaknesses, inadequacies and ways in which they can improve. These methods provoke critical thinking as learners establish the links between what they have learnt and its application in a real life situation (CTSM, 2013; p.22).

What, So-what, Now what

What, So-what, Now-what is a reflective method that allows learners to relate classroom knowledge to real life issues. It is comprised of three components: *What, So-what* and *Now what.* The first part, *What,* involves asking learners to summarise important ideas they have covered in a discussion. *So what* consists of asking learners the importance of what they have learnt. *Now what* involves asking learners the course of action they will take about a problem (CTSM, 2013).

This method is especially useful when teaching science because the teacher's task is not only to transmit knowledge but also to inculcate an interest in civic action and a sense of agency in learners, thereby equipping them to solve the numerous challenges in our society (Westheimer & Kahne, 2004). It is, therefore, not very useful if learners only know about the sources of water pollution but are not motivated to help reduce pollution in their communities. Therefore, during a science lesson on this topic, a teacher could ask learners to summarise the causes of water pollution (*What*). Beyond that, s/he could ask learners about the relevance of this lesson to their own lives and that of their society (*So What*). After this discussion, they could suggest ways of reducing or eliminating water pollution in a water source near their school (*Now What*).

Socratic questioning
To use Socratic questioning in teaching is to use thought-provoking questions to stimulate critical thinking. The teacher poses questions that are meant to inspire learners' critical thinking and to generate in them the excitement to learn more. It also promotes listening, synthesis and evaluation skills that promote critical thinking. This method can be used any time during a lesson but can be extremely helpful at the anticipation stage of a lesson.

There are at least six types of Socratic questions that a teacher could ask:

1. *Questions for clarification*: What do you mean by that? Why do you suggest that?

2. *Questions that probe assumptions*: What are some other possible assumptions? How could you test your assumption?

3. *Questions that probe reason and evidence*: What do you think is the cause of …? What evidence can you provide? What is another example of…"

4. *Questions about viewpoints and perspectives*: What is another way to think about …? What are the strengths and weaknesses of your argument?

5. *Questions about implications and consequences*: What are the implications of this perspective? Why do you consider this to be the best solution/option?

6. *Questions about the question itself*: How does … relate to our everyday lives? Why do you think I posed this question?

(Source http://www.umich.edu/~elements/probsolv/strategy/cthinking.htm)

In almost any topic in the science curriculum, teachers could introduce some of these questions to promote higher-order thinking among their learners.

Research methods
Research methods can be powerful tools in increasing learner engagement and stimulating their critical thinking. "Research methods engage learners into a process of inquiry in order to discover facts, review a theory or develop a plan of action based on the facts discovered" (CTSM, 2013; p. 19). Using research methods in teaching provides immense support to the development of critical thinking skills because research originates from curiosity, which is an investigative skill. By using research methods in teaching, teachers are helping learners to identify societal problems and finding possible ways to solve them. This will happen alongside developing learners' sense of questioning and the need to investigate and find answers for themselves.

Experiments
Experiments are one of the most common research methods in science because we use them to test hypotheses and to compare results from an experimental group and a control group. It is important for learners to learn the basic elements of the scientific method even when they are primary learners because this will help them to develop scientific modes of thinking at a young age. In addition, science experiments may help learners improve their health and the health of their families, and in the process enabling them to see how science in school relates to their daily lives.

There are many sources that provide teachers with ideas for experiments appropriate to primary school learners, but many of them call for resources or equipment that are not found in the typical Malawian school (see *Recommended Readings* at the end of the chapter). Thus, teachers should share ideas with one another when they find appropriate experiments to perform in schools with limited resources. Some ideas for relevant, low-cost experiments include:

- Filtering water from polluted sources using a thin cotton cloth and observing changes in the colour and cleanliness of the water.
- Comparing the growth of the root systems of two seeds planted in clear glass or plastic cups, with one seed serving as the control seed that only receives water and the other the experimental seed that receives water and organic matter like ground egg shells or decomposing fruit/vegetables.
- Observing the effect of salt on water composition by studying how an egg floats or sinks as more salt is added to the water.

Service learning
Service learning may not always involve research, but it can when learners work with organisations on important social problems and investigate the ways they are trying to address them. Service-learning should include "a cycle of action and reflection as learners work with others through a process of applying what they are learning to community problems" (Eyler & Giles, 1999; p.12). It is also important that learners learn to reflect upon their experiences as they seek to achieve real objectives for the community and deeper understanding for themselves" (ibid.). Because science classes should aim to teach learners to think critically and scientifically for the rest of their lives, one of the best ways to learn about how science relates to everyday life is through participation in activities such as those of service learning organisations.

Effective service learning experiences require a great deal from teachers and learners, but it can be well worth the effort. The following are some important elements for a successful service learning program:

i. *Preparing and designing*
Effective service learning that will promote critical thinking needs careful planning and preparation. Teachers should identify which topics in the syllabus are best placed for service learning. They should also consider potential community partners and reach out to them before the school year begins. In agreeing to work with the partner(s), there must be clarity in terms of the expectation of everyone involved, and all participants should demonstrate significant commitment to the exercise. It is

possible that a community partner might pull out at the last minute. This makes having a backup plan/partner important.

ii. *Implementing a service experience*
During the implementation of service learning, there must be a flow of communication between teacher(s) and the partners, as well as with the learners. Logistical considerations made at the preparatory stages will need effective implementation, and these include issues such as transportation to and from the partner's site, provision of work materials and enforcement of agreed rules of engagement. If not addressed in advance, these issues could undermine the whole experience.

iii. *Learning through reflection*
A key part of service learning is reflection by learners on this experience. Teachers need to create opportunities for learners to examine and question their beliefs, opinions and values as they experience new meaning and knowledge. This can be done through writing exercises or brief oral reports during class.

iv. *Assessment*
Assessment is crucial in service learning. This is the extent to which the goals of service learning have been met. This might include attendance records, change in learners' views on the population served by the organisation as well as measurable knowledge that has been acquired by their participation in service learning. Such assessment need not be only for learners. Teachers can also assess the partnership arrangement and the extent to which the partnership should continue. The partner, in turn, can assess both the school and the learners and request modifications in structure and form for subsequent sessions.

There are many organisations in every community that could be suitable sites for service learning, but it depends on a number of factors, including their availability, distance from the school, age of learners and, in some cases, the learner's gender as teachers must think about the safety and well-being of their learners when they are in the community engaged in school-related activities. Some possible service learning sites for science learners include clinics, hospitals, NGOs working to improve community nutrition and health, environmental organisations and companies that employ scientists and may be interested in having learner interns.

Conclusion

In this chapter, we have seen that the process of cultivating learners to become critical thinkers requires thorough preparation, active participation, patience and knowledge of science content. The primary methods we reviewed in this chapter are exposition, cooperative learning, reflective methods and research methods. These can be very useful in promoting critical thinking when teachers include them in a carefully- planned science program.

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Teacher Education in Sub-Saharan Africa. (TESSA). Available at: http://www.tessafrica.net

CHAPTER FOUR

Science Assessments that Stimulate Critical Thinking

Introduction

Assessment in science communicates the expectations of teaching and learning science to all who are involved in it. As stated in the previous chapters, critical thinking in science education emphasises guiding learners to understand and evaluate the subject matter through critical, scientific thinking. For this to be properly determined, assessment tasks should require learners to apply scientific knowledge and reasoning to situations similar to those they will encounter in the world outside the classroom or laboratory.

There are two types of assessments that are carried out in schools: assessment **for** learning and assessment **of** learning. The former is the type of assessment that happens during learning; it seeks and interprets evidence for use by a teacher and a learner to decide where learners are in their learning, where they aim to be, how to get there efficiently and what the next steps should be to advance their learning because learning is a continuous process. This is what we mean by formative assessment, and it goes hand in hand with critical thinking because the development of such thinking requires effective ways of assessing learning as it happens. In contrast, assessment *of* learning is known as summative assessment, and it is carried out most often at the end of a thematic unit, school term, or school year. It's mainly used for the purposes of grading, ranking and reporting learners' performance.

Classroom-based assessments strategies can play an effective role in encouraging learner-centred teaching practices. The traditional teacher-designed summative tests try to assess recall and content questions to test memory, but this tends to limit learning to lower-order thinking as described in Bloom's taxonomy. Research has shown that a change in the type of classroom assessments can play an important role in supporting more effective learning and higher-order thinking, and improving the nature of classroom practice (Price et al, 2011).

This chapter discusses principles for developing assessment, both summative and formative, which stimulate critical thinking. It lays out some general principles for assessment in science that are consistent with critical thinking, and it provides examples of how teachers can use these principles in the development of formative and summative assessments.

General principles for developing assessment that stimulates critical thinking

The following are general principles for developing assessments in science that stimulate critical thinking. Specific principles together with examples for both summative and formative assessments are given in the next two sections.

(a) *Should reflect core educational values.* Assessment in science should be authentic. Rather than checking whether learners have memorized certain items of information, assessment needs to probe for learners' understanding, reasoning and utilization of knowledge. Learners should be assessed on how they can apply understanding and evaluation of information outside school (in everyday) environment (National Research Council, 1996).

(b) *Most effective when assessment reflects an understanding of learning as multi-dimensional, integrated and revealed in performance over time*. Both formative and summative assessment should reflect what learners can do with what they know. In science, scientific inquiry, problem solving methods, strategies and reasoning must be part of what is being assessed because this is where learners will demonstrate critical thinking and understanding of what they have learnt. They should be asked to formulate problems, predict solutions by formulating hypotheses, test their hypotheses and draw meaningful conclusions from these. (ibid.).

(c) *Requires attention to outcomes and experiences that lead to those outcomes.* Assessment in science should reflect the outcomes of science education, including the ability to inquire and to know and understand scientific facts, concepts, principles, laws and theories. Opportunities to learn science must also be assessed. Learners cannot be held accountable for achievements unless they are given adequate opportunities to learn (ibid).

(d) *Works best when it is ongoing not episodic*. To ensure improvement in teaching and learning programmes over a longer period of time, assessment should occur on a regular basis rather than happen only at the end of a term or school year. By using ongoing, formative assessment, teachers can modify their methods as needed, and learners can identify where they need more assistance in order to reach the desired learning goals.

(e) *Has more of an impact when it begins with issues of use and illuminates questions that learners care about.* If learners cannot see the connection between an assessment and the issues they care about, the assessment process reduces itself to a routine where both teachers and learners can go through an assessment process but with little meaning for them. In contrast, when assessments are based on the curiosity of learners, they develop particular interest in the feedback, using it to evaluate their own learning and repositioning themselves for improved learning experiences (CTSM, 2013).

(f) *Most likely to lead to improvement in class performance when it is part of a larger set of conditions that promote the teaching and learning processes.* Assessment should aim at enhancing the quality of teaching and learning in schools. In particular, formative assessment should inform the teaching and learning processes with the intention of offering immediate feedback and greater improvement.

(g) *Assessment as part of being responsible to learners and to the public*. Assessments must be prepared in such a way that outcomes are used for the benefit of learners, parents and the public in general. After assessments have been completed, learners should be given information about their progress in terms of learning goals and expectations. The public should also be made aware of what is going on in their schools and information from learners' performance is one of interest (CTSM, 2013). They, too, want to know about the quality of teaching and where schools in their community lie in the performance of mathematics in a district, region or country.

Specific principles for the assessment of science that stimulates critical thinking
This section will discuss specific principles for summative and formative assessment in science aimed at the primary school level.

1. Summative assessments, although carried out periodically and not effective for providing information at the classroom level to make instructional adjustments and interventions, measure certain aspects of the learning process. These aspects include: learned skills and concepts; creative thinking; inquiry; evaluation; information processing; problem solving; reasoning; communication; etc. These are important aspects of critical thinking. The following are some of the assessment criteria for summative assessment in science that promote critical thinking. They are based on the general characteristics of a critical thinker described in Chapter 2.

   (a) *Raising vital questions*. This means that learners are able to formulate clearly and precisely vital aspects of the problem or reformulate the problem/question. For example, they should be able to assess information given in a word problem:

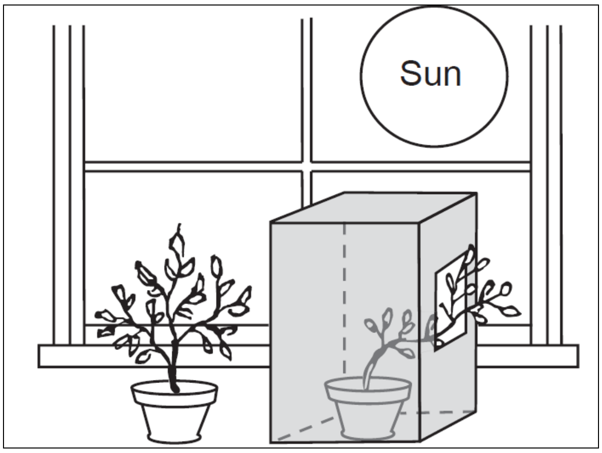
   Example 4.1
   People sweat to help maintain body temperature. What type of feedback happens when sweating regulates body temperature?

   A. Positive feedback, because sweating can increase body temperature
   B. Positive feedback, because sweating can decrease body temperature
   C. Negative feedback, because sweating can decrease body temperature
   D. Negative feedback, because sweating can increase body temperature
   (Source: http://www.k12.wa.us/Science/pubdocs/ScienceBioEOCUpdate2012.pdf)

Learners who think critically should be able to reformulate the question and ask themselves, "What do I know about maintaining body temperature?" "What do I know about the purpose of sweating for our bodies, and is it a positive or negative purpose?" "Why is the increase or decrease of body temperature regarded as positive or negative feedback?"

   (b) *Gathering and assessing relevant information*. Critical thinkers should be able to identify the relevant information in a problem and show clearly the methods used to conduct a science experiment intended to solve the problem. The following is one such example:

   Example 4.2
   A learner placed two plants, A and B, near a sunny window to study plant growth. Plants A and B were the same type of plant and received the same amount of water. Plant B was covered with a box that had a hole cut into its side. The results after several weeks are shown in the diagram.



- Explain why plant B grew out of the hole in the box.

(Source: http://www.nysedregents.org/grade4/science/616/els62016-testw.pdf)

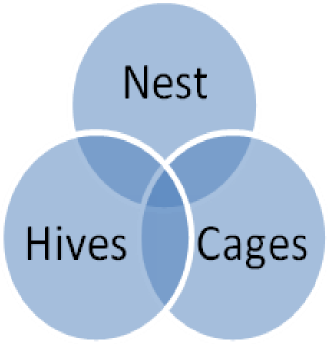
A learner who thinks critically should be able to gather relevant information from the picture regarding the position of the sun in relation to the hole in the box and to assess the relevance of sunlight in their explanation about the direction of plant B's growth.

(c) *Making reasonable predictions and arriving at well-reasoned conclusion*. Learners should be able to demonstrate in any summative assessment how they arrived at well-reasoned conclusions based on evidence provided in examination questions and make predictions about what might happen next in a given situation. For example, in 4.2 above, follow-up questions could ask learners to predict whether the leaves on plant B that are still inside the box and the leaves outside the box are likely to be the same colour or different colours, and how they reached their answer. They could also be asked to predict what would likely happen to plant A in two weeks if it were covered with a box with no holes in it.

2. Formative assessment should be carried out frequently in the classroom so that teachers can adjust their approaches to teaching and learners. Classroom-based formative assessments can serve a vital role in the improvement of learners' understanding of science and their ability to think critically in the science classroom and laboratory. Formative assessment activities include: questioning; observation of learners' performance in class, individually and in groups; interviews; formal performance tasks; investigative projects; portfolio; written reports; etc. For formative assessment to be effective in promoting critical thinking in science, the following principles should be used in lesson planning and assessment development.

(a) *Provide insight/information on learners' learning so teachers can adapt and modify their instruction*. Information can be used to inform teachers' instructional decisions, to discuss the learners' needs with them, to structure follow-up lessons and to become more aware of the learners' interests, needs, strengths and weaknesses to modify instructional strategies for optimal learning. For instance, teachers can ask learners for homework to compare and contrast shelter types for birds by drawing a Venn diagram (see the Mind Map in Chapter Three):

Example 4.3



If the information learners provide is not correct, such as the circle above showing *hives*, then the teacher can adjust his instruction to help more learners understand the similarities and differences in shelters for birds and other animals.

(b) *Assess a broad range of skills*. Formative assessment aims to be holistic, which, in the case of science, means that it should include a range of skills like making inferences, analysing relevant data, collaborating with other learners and reflecting on findings. The assessment should not only require learners to demonstrate their knowledge of science content but should go beyond this to encourage higher-order thinking. Rubrics can be used to assess different skills and not only content knowledge.

An example of a formative assessment rubric for Kindergarten to lower primary learners learning science includes the following categories and criteria. These would need to be adjusted and made more complex for older learners.

Standard & Evidence	**Emerging** (Can do with much teacher guidance and prompting)	**Developing** (Some guidance is needed but can do independently as well)	**Using** (Can do consistently and independently. May need occasional prompting)	**Applying** (Can apply skills and/or concepts to new and/or different situations with little guidance)
Investigates Objects, Materials and Phenomena (7.1c, 7.2a)	Learners can begin to make predictions or guesses with guidance. Learners are able to follow simple procedures to investigate ideas but need guidance with more complex steps. With teacher prompting ("what could you do to find	Learners begin to make predictions that are based upon prior knowledge and experience. Learners are able to follow simple and complex procedures with less guidance. Learners begin to investigate their own ideas during observations and explorations by	Learners can independently make predictions that are based upon prior knowledge and experience. Learners are able to follow complex procedures more independently. Learners frequently investigate their own ideas during observations and	Learners make predictions based upon their knowledge, experience, and investigation. Learners may begin to hypothesize with teacher guidance ("I think this… because …") Learners are able to follow complex procedures and/or develop their own

	out?") learners may investigate ideas they have during observations and explorations. With guidance and structure learners can begin to collect simple data or information.	trying different things. With continued guidance learners are able to collect data and information during investigations.	explorations. Learners are able to collect data and information during investigations more consistently and with less structure provided by the teacher.	procedures for investigating. Learners begin to recognize the idea of fair testing. Learners consistently investigate their own ideas and questions and can begin to design structures for collecting data and information during investigations.

Source: http://www.exemplars.com/assets/files/sci_contin.pdf

(c) *Provide learners with new roles to enable them to see assessment as a learning experience*. It is important for learners to understand that assessment is not a form of punishment; instead, it is a way of keeping learners' needs, strengths and weaknesses at the centre of the learning process. In the redesign of assessment tasks, the focus of instruction and assessment moves more toward the learners, with peer and self-assessment suggested as alternate types of assessment. The goal is for learners to become evaluators and to give feedback on how to improve their classmates' work and their own work.

Below is an example of a peer evaluation form that could be tailored to a science class:

Quick Peer Evaluation Form

Name____Class Period______Date_______________

Write the names of your group members in the numbered boxes. Then, assign yourself a value for each listed attribute. Finally, do the same for each of your group members and total all of the values.

Values: 5=Superior 4=Above Average 3=Average 2=Below Average 1=Weak

Attribute	Myself	1.	2.	3.	4.
Participated in group discussions.					
Helped keep the group on task.					
Contributed useful ideas.					
How much work was done.					
Quality of completed work					
Totals					

Source: http://www.lapresenter.com/coopevalpacket.pdf

Another example of an assessment rubric is of the one below for self-assessment on an independent task or at the end of the lesson

Steps	Criteria	√
Understand the Problem	I re-read the question.	
	I underlined important words.	
	I put the question in my own words.	
	I identified the information that was given.	
	I identified what I need to find out.	
	I explained the problem to a partner.	
Make a Plan	I thought about how this problem is similar to problems I have solved before.	
	I thought about different strategies from our class strategy list.	
	I chose one or more strategies from the list.	
	I discussed my ideas about why the strategy would work with a partner.	
Carry Out the Plan	I tried the strategy until I solved the problem.	
	If necessary, I tried a different strategy or I asked for help.	
	I used words, pictures and/or symbols to show the steps I took to solve the problem.	
Look Back at the Solution	I checked to see if my answer makes sense.	
	I checked to see if there is a better way to solve this problem.	
	I wrote a short explanation describing how I solved the problem.	
	Adapted from The Ontario Curriculum, Grades 1-8, Mathematics	

Source: Learning Goals and Success Criteria, 2010

After completing the peer assessment or self-assessment rubrics, there might be a need to set goal(s) for learners in order to improve or to achieve higher grades. One way to do so is to use the SMART strategy for goal setting. SMART stands for Specific, Measurable, Achievable, Relevant and Timely (Blanchard, Zigarmi, & Zigarmi, 1985). To be specific, learners should say exactly what they will do; measurable means that learners say how they will know if they have met their goal; achievable requires that learners specify the steps they will take to reach their goal; relevant means that learners state what makes a goal important to them; and timely refers to when learners want to complete their goal. An example of a goal that may be set by a learner with the science teacher's support is:

S: I want to be able to construct a parachute using only plastic bags and string that will fall slowly to the ground.

M: I will measure how long it takes my parachute to fall and will make adjustments to its design as needed.

A: I will design the parachute using instructions in our science textbook and will work on it each day after school.

R: I want to be an engineer who designs instruments that can fly.

T: I will complete this task in one week's time – on [learner adds the date].

Rubrics can be useful in assessing assignments, and they are a good way to assess IBL tasks. Teachers may use a rubric as a grading guide to let learners know the areas they want to assess and the criteria for different levels of achievement in each area. The following is an example of a generic rubric for a research based assignment.

Inquiry-Based Learning Rubric

Name:________________________________

Overall Level______

Categories & Expectations	Level 1	Level 2	Level 3	Level 4
KNOWLEDGE & UNDERSTANDING **Understanding of content**	The student shows limited understanding of the content.	The student shows some understanding of content	The student shows good understanding of content	The student shows insightful understanding of content
THINKING **Use of problem solving skills & creative/ critical thinking processes**	Able to: - initiate own learning -solve problems -use creative/critical thinking processes to create final product -reflect on their learning with limited effectiveness	Able to: - initiate own learning -solve problems -use creative/critical thinking processes to create final product -reflect on their learning with some effectiveness	Able to: - initiate own learning -solve problems -use creative/critical thinking processes to create final product -reflect on their learning with considerable effectiveness	Able to: - initiate own learning -solve problems -use creative/critical thinking processes to create final product -reflect on their learning with a high degree of effectiveness
COMMUNICATION **Communicate ideas orally and written**	Able to represent his/her thinking orally and on paper (illustrations and/or text) with limited effectiveness	Able to represent his/her thinking orally and on paper (illustrations and/or text) with some effectiveness	Able to represent his/her thinking orally and on paper (illustrations and/or text) with considerable effectiveness	Able to represent his/her thinking orally and on paper (illustrations and/or text) with a high degree of effectiveness
COMMUNICATION **Knowledge Building Circle**	Able to state wonderings, present questions and listen to others ideas with a limited effectiveness	Able to state wonderings, present questions and listen to others ideas with some effectiveness	Able to state wonderings, present questions and listen to others ideas with a considerable effectiveness	Able to state wonderings, present questions and listen to others ideas with a high degree of effectiveness
COMMUNICATION **Use of vocabulary, terminology, organization & conventions**	Able to use conventions, vocabulary, and terminology related to topic. Information is not organized.	Able to use conventions, vocabulary, and terminology related to topic. Information has some organization.	Able to use conventions, vocabulary, and terminology related to topic. Information is clearly organized.	Able to use conventions, vocabulary, and terminology related to topic. Information is effectively organized.
APPLICATION **Making connections**	The student makes a limited number of connections between the project and the world outside the school.	The student makes some connections between project and the world outside the school	The student makes a variety of connections between project and the world outside the school	The student makes a wide variety of connections between project work and the world outside the school

Source: https://www.rrdsb.com/sites/www.rrdsb.com/files/sss/NSCS_Inquiry-Based_Learning_Rubric.pdf

(d) *Focus on how learners learn using effective questioning.* Both teachers and learners must be aware of how learners are going to learn a specific concept. Chapter Three discussed methods and strategies of teaching science that promote critical thinking. When the teaching and learning processes are happening, one method that cuts across all methods is the question and answer method. This method is effective in guiding learners towards the intended learning goals. It is therefore key to effective formative assessment. To promote critical thinking and encourage responses from learners that involve scientific reasoning, teachers should consider the following:

- *Ask higher-order thinking questions*. Teachers should make frequent reference to Bloom's taxonomy as discussed in Chapter One and create problems that call on learners to use these higher order skills. For example, a question like the following requires learners to classify and not only list: "How would you *classify* these 10 animals (teacher shows pictures of them) into the categories of reptiles, amphibians and mammals?" The learners must examine the properties of these animals as they classify them.

- *Give thinking time.* Teachers should allow learners sufficient time to think about possible solutions to any questions posed by the teacher before asking them to respond. This will provide learners opportunities to give meaningful answers (or sensible attempts) and will encourage those who are slower to respond and share their thinking as well. When this happens, the teacher receives more feedback from the class as a whole to support and guide their learners' progress.

- *Involve as many learners as possible in answering and asking questions*. This is important for teachers to do in every class so that everyone feels respected and are part of the learning community. Teacher should frequently pick learners who are not putting their hands up because these learners may also know the answer or have an attempt at an answer that would benefit the entire class if they heard it. The more learners are involved in their learning, the more they are prompted to think, and think critically, because they are more motivated and engaged.

(e) Provide feedback. Feedback is the most powerful tool that teachers have to help improve learners' learning, and it is a formative type of assessment if it is given frequently and in a timely manner. To give learners effective feedback that promotes critical thinking, science teachers should consider doing the following:

- *Engage learners in self-assessment and self-reflection*. Teachers should allow learners to talk about and display their work, and allow them to demonstrate their understanding of science concepts and experimental methods of different types.

- *Remind learners frequently of learning outcomes and success criteria.* Teachers can guide learners to know the progress in a lesson if they make these reminders at the beginning and throughout a lesson. They should also display high expectations for learners and describe to them the qualities of high-quality work in relation to the
learning objectives and success criteria. This can be done by using rubrics, as discussed above, and models and examples of strong and weak work. For example, if the success criterion is to "record each step you did to conduct the experiment," then skipping even one step may be evidence of weak performance and may need improvement.

- *Use descriptive rather than evaluative feedback. Teachers should provide clear,* specific information in the form of oral or written comments to help learners understand what they need to do to improve their work. They can also involve learners in setting up goals to excel. However, meeting the intended learning outcomes should not be the limit for learners—teachers should allow and support higher achievers to go beyond learning outcomes (or above success criteria).

Examples of descriptive feedback in science include the following:

- *This is quality work because you made detailed observations of your plant as it grew from a seed to a flower.*
- *Two things you could do to improve your work: 1) When you are making observations in your science notebook, you should always include the date and time of the observation. 2) When you are drawing conclusions based on your observations, you should use precise scientific terms like 'germinate', 'evolve', and 'mature'.*

Conclusion

This chapter has focused on assessments that can be used in science classes to promote critical thinking. We have given particular attention to formative assessment because learners' difficulties in learning science is often as a result of lack of ongoing feedback on how well they are reaching learning objectives with only final, end-of-term summative assessments being used in some classrooms. When learners understand that the purpose of assessment is to enhance their learning throughout a unit, they tend to concentrate better and participate more. In addition, the chapter has pointed out that low achievement is often as a result of learners failing to understand what teachers expect them to do and how well-designed assessments can improve this situation (Black & Wiliam, 1998).

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CHAPTER FIVE

Integrating Critical Thinking Across the Curriculum

Introduction

The development of critical thinking is an important goal of primary education in Malawi. According to Beyer (1985), "critical thinking has two important dimensions. It is both a frame of mind and a number of specific mental operations" (p. 271). Having a critical spirit is as important as thinking critically. The critical spirit requires one to think critically about all aspects of life, to think critically about one's own thinking and to act on the basis of what one has considered when using critical thinking skills (Norris, 1985). Being a critical thinker also requires developing particular attitudes or dispositions such as respect, cooperation, ability to listen and to deliberate.

A very powerful environment for promoting critical thinking is created when teachers are able to integrate it across the curriculum by thinking about how to connect their particular subject-humanities, languages, mathematics or science—with other subjects. Such connections are useful for developing learners' higher-order cognitive skills, such as analysis, evaluation, and synthesis. When one subject area reinforces content in the others, learners begin to identify and understand relationships between concepts and develop new understandings across the curriculum.

This chapter will discuss ways for integrating critical thinking across the curriculum and provide examples of how teachers in humanities, languages, mathematics and science can support the learning of content and critical thinking skills in each of their subject areas.

School-based support for integration of critical thinking across the curriculum

It can be a challenging experience for teachers to design lessons that create opportunities for critical thinking *and* to find ways of supporting learning of other content areas. However, learners who experience such integration learn to synthesise information from multiple sources and evaluate it in a more sophisticated manner. For instance, learners may learn in their life skills class about how to prevent malaria, but their learning moves to a higher order when this information is connected to a language activity in which learners write about a time when they were sick and to mathematics lesson in which learners learn to multiply numbers using the reproduction of malarial parasites in the bloodstream as an example. When content and critical thinking skills are infused throughout the curriculum, there is continual reinforcement of core content throughout the school day and opportunity to think about it from different perspectives.

School leaders, such as head teachers, play a critical role in creating the conditions that allow teachers to integrate critical thinking across the curriculum. Teachers need to work together and determine the following:

- How best to prompt learners to use different strategies to think about the content they are learning in each of their classes.
- How to encourage learners' development of higher-order thinking skills that can be used in every subject area.

- How to relate the content in one class to the content of others to stimulate greater interest by learners in what they are learning.

The following strategies can be used to create a holistic, school-wide approach to teaching critical thinking:

- Teachers work with school heads to develop a system by which teachers who teach the same learners (all Standard 3 teachers, for example) are allocated time every two-three weeks to share with their fellow teachers the content (topics) they are working on in their humanities, languages, mathematics or science classes and how they are trying to promote critical thinking during these lessons.

- Teachers identify vocabulary, stories, experiments, field trips and other activities that would reinforce the learning of content across two or more subjects, and they share with one another the specific critical thinking skills they seek to develop in carrying out these activities.

- Teachers visit their fellow teachers' classes whenever this is feasible and provide peer feedback in a supportive, non-evaluative manner on how their colleagues could continue to improve their use of critical thinking methods and strategies to teach content across the curriculum.

- School heads allocate time each month when teachers can share with one another a particularly effective method for promoting critical thinking they have recently used in the classroom. They can also use this time to discuss how the school can promote curriculum integration through the development of themes that are relevant to more than one subject and that promote critical thinking. If time is limited, two teachers could be selected each month to share examples of how they are working to integrate a common theme in their classes and the critical thinking skills they are building into this theme. As teachers become more comfortable with this form of school-based professional development, they can also be encouraged to discuss efforts at integration that did not work as well as planned or critical thinking methods that did not seem effective. Their colleagues can provide feedback on how to make their efforts more successful.

Classroom-based strategies for critical thinking integration across the curriculum

Teachers can do a great deal to encourage critical thinking and curriculum integration. It can be done in many different ways using simple strategies, such as, on a Friday, asking different learners during the humanities class to mention something they learned in their language class that relates to their learning in humanities that week. This strategy builds oral proficiency and can be used to develop summarizing skills. Critical thinking and curriculum integration can also be much more elaborate, as when an accountant from the community is invited to come to class and talk about how s/he uses mathematics, and the language and literacy teacher, later the same day or the next day, asks learners to role play being an accountant and client or to write a story about an accountant who does not know how to multiply numbers.

In preparing to use an integrated approach, teachers should:

- share their plans with their fellow teachers to make sure important content has been covered or activities (such as a guest speaker) have occurred as scheduled;
- identify the concepts and skills in their content areas that they seek to reinforce by drawing on content in other classes;
- asks reflective questions to guide learners toward analysis, evaluation and synthesis of concepts or facts learned in two or more subject areas; and
- reinforce critical thinking by providing ample opportunities for learners to engage in thinking independently.

In integrating critical thinking across the curriculum, it is important for teachers to consider the following points about learning:

- The interdependence between content and thinking means that teachers should strive to incorporate critical thinking skills into a wide variety of subjects, situations, contexts and educational levels. Learning a subject means learning the terminology, understanding the concepts, being able to discuss and write about it critically and to transfer this subject knowledge to other contexts.

- Critical thinking can and should contribute to achieving learning outcomes through assessment. This can include content understanding, recall and communication skills as well as skillfulness in thinking.

- Interaction during instruction should be encouraged because it allows learners to share ideas, confront different and even conflicting perspectives, challenge views of other people or to be challenged and defend their own perspectives. They learn from each other by collaborating and deliberating, all of which ultimately contributes to their critical thinking. Such interaction creates a constructive avenue for learners to learn and experience a democratic way of living.

- Classroom conditions that stimulate critical, creative thinking are necessary so that learners are encouraged to make inferences, think intuitively and spontaneously and use inquiry-discovery teaching techniques. Learners need to feel free to suggest and experiment with new ideas and approaches.

Specific strategies: Integrating humanities, languages, mathematics and science

(a) *Word walls*: Teachers can identify a space on one wall in the classroom where important vocabulary can be recorded. The word wall can be specific to one subject (Figures 5.1a and 5.1b) or, if teachers share a classroom, the word wall can have key terms from different subjects on it (Picture 5.2) This kind of visual reinforcement of key words helps to build language and literacy skills, and it encourages learners to synthesise vocabulary learned in different subject areas if teachers develop questions and other activities that require them to do so.

Figure 5.1a: Science word walls

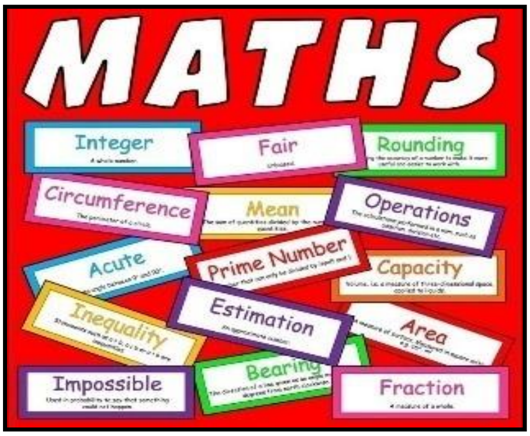

Figure 5.1b: Mathematics word wall

Figure 5.2: Multi-subject word wall

(b) *Word tree*: A word tree can also be used to stimulate lower order and higher order questioning in the humanities, languages, mathematics and science (Figure 5.3). This word tree can be exhibited on the classroom wall and a conversation or a questions session to stimulate critical thinking on any topic could be guided by these questions. This strategy is suitable for use in Kinder or lower primary and senior primary.

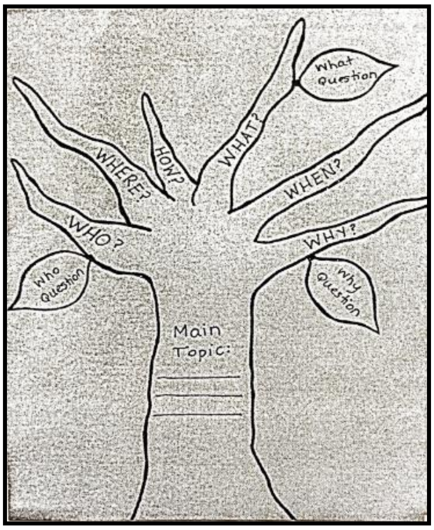

Figure 5.3: Multi-subject word tree

(c) *Drama:* There are many ways that drama in the form of role-playing and plays can be used to develop content knowledge in the humanities while also reinforcing listening, speaking, reading and writing skills in the language classroom. Religious education has stories that can be retold in the form of a full-length play or as a short role play, and the learners could be required to use certain word forms or grammatical structures that they are studying in their languages class. A play could also be developed that addresses the topic of gender and entrepreneurship from the life skills component of the humanities curriculum. In the play, learners could have some of the characters doing the mathematical calculations they have been studying in their mathematics class. By developing their own script, learners would have to synthesise information from life skills and mathematics classes and analyse the kind of mathematics problems an entrepreneur in a particular field might need to do.

(d) *Stories and story problems*: Every subject in the curriculum requires some degree of reading, and the creative use of stories can lead to curriculum integration and critical thinking. For instance, reading passages in language classes can be based on historical narratives related to a topic in religious education or life skills, and story problems in mathematics can be connected to content in life skills classes. Teachers in each subject could use these texts as prompts for learners to think more deeply about their particular subject and the complementary subject area through the use of questions that promote critical thinking.

(e) *Analysis of charts and graphs:* Many topics in the curriculum require learners to analyse charts or graphs, such as topics related to population size, economic growth and languages spoken in different countries. Learning how to make sense of these visual representations requires mathematics, and this can serve as an important connection between mathematics and other subjects, and between mathematics and the daily lives of learners. When learners understand how to analyse charts and graphs, they will be able to think more critically about how these visuals are used in the media and whether they are being used properly.

(f) *Experiments and field trips:* As mentioned earlier in this chapter, teachers can work together in many creative ways. This helps to integrate and reinforce the curriculum and it also saves time, money, and teachers' energy when they do so. For example, the science teacher and the humanities teacher could work together to create an experiment or an outdoor observation that addresses a topic that is in the Social Studies curriculum. The same could be done with the mathematics teacher who might want to teach learners about graphing what they observe during an experiment. Field trips are also desirable when organised well and involve critical thinking on the part of learners, but they can also be costly; however, when two or three teachers work together to develop a field trip, the field trip would reinforce content in all of their subjects. Teachers can think creatively about what such sites might be (hospitals, manufacturing plants, national parks, etc.) and how a trip to the site could serve as the basis for activities in humanities, languages, mathematics and science.

Conclusion

This chapter has introduced the importance of reinforcement of content and critical thinking across the curriculum. Strategies that school leaders and teachers can use to support such work have been provided. The chapter also described a number of specific ways that teachers in the humanities, languages, and mathematics can integrate key content from their particular subject areas with content in other subjects. This demonstration of how information can be synthesised and analysed from different perspectives will help learners to do the same, thereby strengthening their critical thinking skills.

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