Teaching Inquiry-based Science

Mark Walker

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A GUIDE FOR MIDDLE AND HIGH SCHOOL TEACHERS

Mark D. Walker

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CONTENTS

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I would most like to acknowledge my former employer Prof. Kirsten Schlüter from the Department of Chemistry and Biology at the University of Siegen, Germany. She gave me the opportunity to work with her developing and finding out about inquiry-based science. I found this work interesting and enjoyable. This was a surprise to me initially. I had always had a rather negative view of teaching. Teaching, I thought, was easy. All you had to do was stand up and say what you knew. It was only while learning about inquiry-based science that I realized it is much more than this. Teaching is an art. It is easy to know something, but much more difficult to communicate that to someone else in a way they will remember. Teaching is a skilled and specialist ability, which not everyone can do. I would like to thank Prof. Schlüter for letting me find this out.

I wrote much of the text parellel to the work I was doing for her. I would like to thank her for the support and understanding she showed while I was doing so. I hope the readers, learn to appreciate and use inquiry in their own classrooms as I feel this would be the best thanks that she could have.

I would also like to thank Angelika Kremer, Bernd Mosler, Dr. Wolfgang Poltz, and Dr. Martin Gröger from the Department for Chemistry and Biology at the University of Siegen for their ideas and support in our research and work into inquiry-based science teaching.

ABOUT THE AUTHOR

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HOW TO USE THIS BOOK

This book is designed for middle or high school science teachers wishing to learn more about using inquiry-based science in their classrooms. The book is intended to be a short and concise introduction to inquiry-based science. It aims to be practical, offering a number of examples of inquiry-based science that you could use in your classrooms. However instead of simply providing examples I have tried to write a book which acts as a guidebook, offering general methods which you can use yourself to develop inquiry-based lessons of your own. You don't just want a list of examples; you want to have the tools that enable you to teach what you want. This book tries to suggest general methods that can be used by a teacher and integrated into lessons of their own design. Only when teachers learn how to organize and manage inquiry-based lessons of their own design, without recourse to the examples provided in a textbook will inquiry really become widespread in our schools.

The book is divided into 4 sections. The first section is the 'theory' section where the basic ideas behind inquiry are covered. Most existing teachers will have come across this material before and may find little of interest here. It is included here simply for completeness. The first chapter explains what inquiry-based science is and provides a simple introduction to inquiry. The chapter about scientific inquiry is recommended to those of you with a non-science background, as this area is often neglected in other books about inquiry. The third chapter provides information about the constructivist theory of learning. These first few chapters provide the foundations for inquiry-based science.

The second and third sections are more practical and personal in tone. The second section contains a chapter about what an inquiry-based lesson needs to contain and a chapter giving a simple example of an inquiry-based lesson using pendulums. Hopefully after reading the theory these chapters will show you what an inquiry-based science lesson actually looks like.

The third section goes onto provide practical methods and ideas of use in the classroom. Chapter 6 provides different methods and techniques that can be used in inquiry teaching. Chapters about teacher questioning, classroom management, evaluation and assessment, and why teachers might be reluctant to use inquiry are also provided.

There are many different ways of teaching inquiry and some of these different ways are shown in the final section. Here you can find a chapter about how to convert existing non-inquiry activities into inquiry-based ones, a chapter about more long-term inquiry work and a chapter looking at the different ways of doing science. The section ends with a list of possible title ideas for inquiry lessons you can use to develop your own lessons.

PREFACE

I studied biology at university and as part of my studies I had to take courses in plant biology, an essential topic for any biology student. The professor who lectured me on this subject was an old man nearing retirement. He would stride into class with a heavy volume about plant biology he had written about 40 years previously. His lectures consisted of opening his book at the desired chapter and reading aloud from it for the duration of the lecture. At the end of each session he would instruct us to read to the end of that chapter for 'homework' thus allowing him to start another chapter in the next lecture.

It is now some time since I left university. I can remember embarrassingly little about plant biology. I cannot name the main groupings of plants. I have a fuzzy recollection of plant physiology. I struggle to explain basic processes that occur in plants. In short I did not learn about plant biology well enough at university. The way in which I learnt was not motivating or interesting enough to make me remember what I had been taught, or to prompt me to do further independent study.

When I decided to write this book I immediately remembered my experience at university, and wanted to use this chance to make sure that other students, at whatever level, were taught in a more stimulating and engaging way than I had been then. Inquiry-based science offers students that chance. Instead of being passive learners in which information is stored, the student become the doer in the classroom, the one who is expected to work out what is happening and the one who must make the decisions. In such a way students remember what they learn best, not just tomorrow or the day after, but for years or decades.

Mark Walker

SECTION:

A

THE THEORY BEHIND INQUIRY-BASED SCIENCE

1

WHAT IS INQUIRY-BASED SCIENCE?

I keep the subject of my inquiry constantly before me, and wait till the first dawning opens gradually, by little and little, into a full and clear light.

Isaac Newton

Inquiry: an old meaning revived

What does the word inquiry mean to you? If you look it up in a dictionary, you will probably see that it means the posing of questions, the finding out of something, the searching out of information, or the carrying out of an investigation. This last meaning is the one this book concentrates on: inquiry as a form of investigation.

The word inquiry used to be used to describe what scientists did when they were finding things out about the world and conducting experiments. The way in which scientists worked was known as a whole 'inquiry.' The quote from Isaac Newton that is given at the beginning of this chapter is an example of this old usage. Today we rarely call the work scientists do 'inquiry', preferring other more modern words such as 'research,' 'investigation' or 'study'. The word inquiry seems old fashioned and stuffy.

But inquiry in its traditional meaning has made a come back and has been used to describe a modern method of teaching science known as inquiry-based science. In inquiry-based science instead of simply being lectured about what they need to know or being told how to conduct experiments by teachers this method of teaching forces students to do what scientists have always had to do when they wanted to find something new and that is to actually do an investigation themselves.

What is inquiry-based science?

Scientists study the natural world. They try to answer questions about the world around them. When conducting research scientists use a number of skills. These skills are called the science process skills. They include observation, description, question finding, planning of experiments, prediction, and experimentation (NRC 1996). Scientists use these skills in a methodical sequence. One such sequence, and the most well known is the 'scientific method,' but there are others. Scientists also possess certain attitudes and beliefs that they have when using these skills and methods. Altogether these different factors make up scientific inquiry; this is what scientists are doing when they are conducting research. Scientific inquiry is actually a good name for the work that scientists do, because when conducting science scientists are trying to find the answers to questions and problems they have and they are inquiring in a scientific way.

Inquiry-based science is a teaching method in which students work in a similar way as scientists when they are doing research. In inquiry-based science the students formulate their own questions, create hypotheses, and design investigations that test these hypotheses and answer the question proposed (NRC 1996, NRC 2000). The work students do in inquiry-based science mirrors the work which scientists do when they are conducting research. To put it simply the students work as 'junior scientists.'

It is important to recognize the differences between inquiry-based science and non-inquiry forms of science teaching. Simply by having students 'do an experiment' does not mean they are engaged in inquiry-based science. In a typical non-inquiry lesson the teacher would explain the important points of the topic being learnt, then the students would be given an experiment to do to reinforce this knowledge. The students would be given a worksheet explaining what methods they had to follow to complete the experiment, and maybe even be told what results they were expected to find. Everything would be written up in a lab book as a lab report at the end of the lesson. A professional scientist working in a research laboratory does not work in such a way.

A lesson taught using inquiry-based methods is very different. The teacher would introduce the topic in some way maybe with a demonstration or by showing the students some interesting phenomenon. Maybe the teacher would pose a problem about the topic to the students, or maybe if the students are advanced enough the teacher could guide the students to find a problem on their own. The students would then be expected to formulate a question about the problem; from this question they would develop a hypothesis. Instead of being given a worksheet, or a detailed list of instructions to follow the students would be expected to develop a method themselves. After the experiment the students would be expected to decide if their initial hypothesis was correct or not and then to try to solve the problem. They are doing more than simply doing an experiment they are working like real scientists.

Inquiry-based learning reflects modern practices within pedagogical science. The constructivist theory of learning is embedded within the idea of inquiry-based learning. This is because the inquiry-based learning idea is based upon how scientists work and scientists themselves work in a constructivist way. This convenient dovetailing of science, science education, and constructivism results in a teaching method that combines the strengths of each discipline. To fully understand inquiry-based science is it necessary therefore to understand the basic principles of science research and the ideas and theory behind constructivism. These topics will be discussed in later chapters. If at this stage inquiry-based science seems very complicated and difficult to understand, and you cannot see how you could teach using it, do not despair! This chapter is only meant to act as a general introduction, the ideas and principles behind inquiry will hopefully become clearer once you have read later chapters and seen some examples.

What are the advantages of using inquiry-based science?

There are two main advantages of teaching science through inquiry. Firstly by using the process of inquiry students remember and understand scientific knowledge better. Secondly while using inquiry students learn how scientists generate knowledge and how the current body of scientific knowledge was developed and produced (Schwab 1962). Once students have learnt how scientific knowledge is produced they can then go on to use the same skills and processes to generate new knowledge for themselves.

Inquiry-based methods of teaching improve student achievement at science. Studies from the early 1980s showed that students who were exposed to science lessons with more hands-on practical work obtained higher test scores and had better science process skills than counterparts taught using more traditional methods (Shymansky 1983, Bredderman 1982, Shymansky et al 1982, Shymansky et al. 1990, Haury 1993). These results are confirmed in more recent studies, which have found that students with teachers who use specific aspects of inquiry in their lesson do better at standard testing (von Secker & Lissitz 1999, von Secker 2002). Students introduced to inquiry study receive higher test marks (Marx et al. 1998, Cuevas et al. 2003).

Apart from increasing achievement levels of students, inquiry-based science also has a positive effect on students' attitudes towards science. Students engaged in inquiry-orientated work find science more interesting and exciting, and had a more positive view of science (Kyle et al. 1986, Gibson & Chase 2002). Generally speaking there is a fall in interest in science amongst students as they enter and proceed through secondary school, and the use of more inquiry-based science, which students see as being more relevant could be a way of combating this (Gibson & Chase 2002).

‚Traditional' ways of teaching science

In the early 1960s it was recognized that the teaching of science in schools was not being effective at producing scientifically literate individuals. There was a perceived danger that as a result of this the U.S. could lag behind other leading powers in science and technological advances. The teaching of science content was seen as the predominant aim of science, and lessons were based to a large extent on textbook reading and exercises. This 'traditional' way of teaching science was well described by Costenson & Lawson (1986):

> "…teaching centered around one fact-laden text, and consisted of assign, recite, test, and then, discuss the test."

This so called 'traditional' way of teaching science emphasized the knowledge of scientific facts, laws, theories and their uses. Laboratory activities were only used as a way of verifying science concepts previously learnt (Costenson & Lawson 1986, Shymansky 1984). Lessons involved students listening to teacher lectures on the topic being studied and readings from set textbooks.

Inquiry as a modern method of teaching science

In response to these failings a number of reform programs and new teaching ideas were introduced. These were based on the idea of inquiry, basically that students should be involved in the asking and solving of questions in science lessons (Chiappetta, 1997). Examples of these early schemes included the Biological Sciences Curriculum Study (BSCS 1970) and the Science As A Process Approach (American Association for the Advancement of Science (AAAS 1975). These schemes emphasized an understanding of the nature of science and science as a process. Laboratory exercises were seen as an integral part of science learning and not just as a confirmation activity at the end of a lesson. Scientific educators such as Schwab (1962), Herron (1971), Tamir (1985) and Welch at al. (1981) all promoted the teaching of science using inquiry like ideas. Such ideas were not new and had first been proposed in the late 19th and early 20th centuries by a number of philosophers, most notably John Dewey (1933) but at the time had failed to be implemented widely.

The reforms of the mid 1960s and 1970s can be seen as the forerunners of today's inquiry-based science, and they share many features of today's inquiry-based science. Unfortunately although these reforms received wide support from science educationalists, like the ideas of Dewey earlier in the century, they failed to be widely implemented in schools. Teaching of science in schools for the most part continued to follow the traditional pattern (Costenson & Lawson 1986).

Once again the failings of science education that was based on the traditional format came to the fore with the publication of the A Nation at Risk report in 1983. This report again highlighted the poor standards of teaching in many of the U.S.'s schools, and suggested that students should gain an introduction to the methods of scientific inquiry and reasoning while at school. The idea of inquiry-based science was further developed and encompassed many of the ideas of the previous reform efforts.

The Science for all Americans and Benchmarks for Scientific Literacy reports

These two documents provided the basis of the later National Standards in Science Education and its emphasis on learning science through inquiry. The first of these documents, Science for all Americans, was published in 1990 and focused on the need for improved scientific literacy. The report highlights the fact that content laden curricula do not necessarily improve student's level of scientific literacy and that a greater emphasis on understanding was needed. Science is divided into a number of chapters showing that learning and understanding about the common elements of science and the interrelatedness of scientific disciplines is more important that factual knowledge in any one subject area.

These themes were continued in the 1993 Benchmarks for Scientific Literacy. This document took the ideas proposed in the Science for all Americans document and provided learning goals for students of science at different stages of their education. As the Benchmarks made clear they were not designed to be used as a curriculum, and they do not tell teachers which teaching methods to use or what exactly to teach. The Benchmarks simply provide a set of science goals; things students should know and be able to do. The idea was that Benchmarks could be used by teachers to build their own curriculum using teaching methods they felt comfortable with. It was hoped that this flexibility would encourage teachers to use varied methods of teaching, not simply 'chalk and talk' or inquiry-based, but rather a good mixture of teaching practices and ones suited to the topics they had to teach.

Scientific inquiry, what science is and how it is conducted, was given especial emphasis making up the first chapter, entitled 'the nature of science' of both Science for all Americans and the Benchmarks. The National Science Education Standards that were published 3 years later was heavily influenced by the ideas proposed in these two documents. However, the main thrust of the National Science Education Standards was that science was an activity best learnt and understood through the use of inquiry-based science.

The National Science Education Standards

Inquiry-based science really took center stage in the mid 1990s, with the publication of the National Science Education Standards (NRC 1996), a key document guiding science education in the United States of America. The idea of inquiry and inquiry-based science was interwoven into this document, and this method was stated as being the best way of teaching science to our children. Inquiry was defined as:

> 'the diverse ways in which scientists study the natural world and propose explanations based on evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world.'

The first part of this statement considers inquiry as being how scientists conduct science; as mentioned this is commonly known as scientific inquiry. The second part of the definition considers inquiry as how students learn science and learn about how scientists work. This is best done through inquiry-based learning, as the standards make clear when they say that:

> 'Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in the light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations.'

The best way for students to learn how to do science and to learn about how scientists think is to actually use the same skills and methods as scientists use in scientific inquiry. This is the central tenet behind inquiry-based science, getting students to work like scientists.

The National Science Education Standards emphasized the importance of getting students to generate their own questions to investigate, ones based on their pre-existing knowledge and experience. The standards make clear that the student and not the teacher should initiate this process:

> 'Inquiry into authentic questions generated from student experiences is the central strategy for teaching science.'

A further report by the NRC, entitled 'Inquiry and the national science education standards: A guide for teaching and learning' (NRC 2000) further extended the ideas presented in the NSES and provided 5 essential features which inquiry should contain;

- Learners are engaged by scientifically orientated questions.
- Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically orientated questions.
- Learners formulate explanations from evidence to address scientifically orientated questions.
- Learners evaluate their experiences in the light of alternative explanations, particularly those reflecting scientific understanding.
- Learners communicate and justify their proposed explanations.

A comparison between a non-inquiry and an inquiry-based science activity

Below are two different activities to teach the same topic: the factors that affect photosynthesis in pondweed. The first activity is not inquiry-based and is a fairly typical example of the experiments commonly conducted in school science lessons. The second activity is more inquiry-based and possesses many of the features seen in an inquiry-based lesson. In this experiment students are not told what to do but are expected to decide for themselves how to conduct the experiment and how to collect results. These two different methods of teaching the same topic are given here to provide a comparison between inquiry and non-inquiry methods, and to try to help you understand the differences between the two. Although the experiments are most suitable for older students of about 9th grade onwards, the principles behind an inquiry-based lesson and the differences between the activities are valid for experiments at every age range.

Non-inquiry activity:

Germination is dependant on temperature

Background Information:
Germination is the beginning of planned and systematic growth of a seed. Just like many other life processes germination is affected by the temperature. In chemical reactions inside living things the speed of reactions increases with increasing temperatures. However, the temperature required for germination to begin can vary greatly depending on the species of plant. Every species has its own optimal temperature for germination to start.

Material:
2 Petri dishes, a thermometer, garden cress seeds, a large clear plastic container kept damp, a fridge.

Time	**Number of germinated seeds**	
	Room temperature	**4 ^{o} C**
24 hours		
3 days		
1 week		
2 weeks		

Questions
What influence does raising the temperature have on germination?
Why do seeds germinate faster when it is warmer?
List 3 factors, which seeds need in order to germinate.

This non-inquiry activity:

- Has a stated goal. Both in the title and in the introduction section the information the student is expected to learn is stated clearly: Germination is influenced by temperature. In this activity the students must only confirm this statement.

- A detailed list of instructions is given in the method section. The student only has to follow the method in order to correctly complete the practical.

- The students do not have to think independently in order to answer the questions. Students must simply regurgitate information contained within the text.

In a non-inquiry exercise such as this one, background information would be provided to the students before they conducted the experiment. For example here some information is given on the worksheet before the instructions for the experiment are given. Sometimes the teacher would give a short lecture to the students providing the background information, or even give them some textbook reading to do before they began the experiment. This background information would contain information about what they were expected to find in the experiment. The student's task would simply be to try to confirm what they had been told or had read when doing the experiment.

Often at the end of non-inquiry experiments, such as this one, students are asked to answer questions using the information they were given before the activity began or which could be found in standard school textbooks. These questions are therefore not questions testing understanding, but rather testing how students knowledge and remembering skills.

Inquiry-based science activity:

Imagine that you work as a scientist in a biological research lab. One day your boss comes to you with a problem he wants you to answer:

'Global warming could be a big problem for farmers all around the world. The germination of some species of plants could be affected. Design an experiment to find out how global warming could affect seed germination in the spring, and if this will be a problem for farmers'.

You have to design and conduct an experiment to find out what effect global warming could have on seed germination. You should:

- Decide which experiments to conduct
- Decide which data to collect
- Do the experiment
- Make a poster showing your results and conclusions

Questions

Which other factors apart from temperature affect germination? How would you conduct an experiment to find out what effect these other factors have on germination?

Your boss gives you a chemical that is able to remove the oxygen from the air. How could you design an experiment to find out if germinating seeds need oxygen? Draw a diagram of how you would set up the experiment.

The more inquiry-based activity:

- The students are not told what the expected results are. Students are simply told to investigate how global warming affects plant growth. In a non-inquiry experiment students might be told that 'higher temperatures caused by global warming will cause plants to photosynthesize more'.

- The students must decide themselves how to set up the experiment and which method to use.

- There is no table for the students to fill in their results.

- The students have to think in order to answer the questions. They not simply copy the answers from their worksheet. The questions ask them how they would conduct further experiments and prompt them to think about new problems, and not simply ask for pieces of knowledge.

This activity forces the students to think much more than the first one. Students do not simply follow the instruction sheet but must decide what to do themselves. They have to plan, design and conduct the experiment themselves. The student has to decide which data to collect, and what it actually means.

Notice that in this activity no background information is given. In an inquiry-based activity the teacher does not provide background information or textbook reading. In an inquiry-based exercise the students are expected to find out for themselves what the result of the experiment is and what it means. The students do not simply confirm information they have already been given, but must find the information for themselves.

Classifying inquiry-based science

There have been numerous attempts at defining and classifying inquiry-based science (Anderson 2002). Inquiry-based science can cover a wide range of different types of activities with varying levels of openness, so it is important to have some way of classifying inquiry lesson and deciding how inquiry like they are.

Schwab and Herron's scale of laboratory openness

Schwab was one of the first science educators to develop the concept of inquiry-based science. He wanted to make laboratory work more like real scientific experimentation. His book 'The teaching of science as enquiry' (Schwab, 1962) paved the way for the development of inquiry-based science in the 1970s. Schwab was the first to try to classify inquiry. He recognized three levels of inquiry science. In his first level the teacher posed a problem, which students then tried to answer by using different methods. In the second level the teacher posed a problem, but this time the students had to develop a method themselves. In the third level of inquiry the students had to both pose the problem and develop a suitable method.

Herron later extended and refined this way of looking at inquiry. He developed what is known as the Schwab-Herron Scale of Laboratory Openness (Herron 1971). This possessed an additional level of inquiry, and could be expressed in tabular form. This shows who should provide or do what in a laboratory exercise. An example of this scale is provided below.

Level	Problem	Method	Results
0	Given	Given	Given
1	Given	Given	Student
2	Given	Student	Student
3	Student	Student	Student

Structured, guided and open inquiry

Tafoya et al. (1980) produced a simple method of classifying inquiry, depending on who provided the question on which a lesson was based upon. This is based on Schwab and Herron's ideas, but is expressed in written form and not tabular. Inquiry was divided into structured, guided or open. This method of classifying inquiry was easy to understand and easy to use and has found wide acceptance.

Inquiry-based science lessons can be either:

- **Open:** The lesson is wholly inquiry-based. The students decide on the problem and question to investigate and the method to use to answer it.

- **Guided:** In guided inquiry the teacher provides the question that needs to be answered. The students decide on the best method in which to answer this question.

- **Structured:** In structured inquiry the teacher provides the students both with the question to be answered and the method to use to answer it, but not the expected outcome. The only difference between structured inquiry and confirmation exercises is that in structured inquiry the student does not know the outcome of the experiment.

- **Confirmation Exercises:** these are not inquiry-based at all. In confirmation exercises the teacher tells the students what the solution is to the question at the beginning of the lesson, and then gives instructions of how to conduct an experiment to confirm this.

These different categories of inquiry can be seen as being analogous to Schwab and Herron's levels of inquiry, with confirmation exercises being at inquiry level 0, and open inquiry being at level 3. Here is an example of how an activity about the rate of photosynthesis in pondweed, could be taught with these different grades of inquiry:

- **Open**: Students are told to 'investigate the factors which affect the rate of photosynthesis in pondweed'.

- **Guided inquiry:** Students are told to design and conduct an experiment to answer the following question 'how does light intensity affect the rate of photosynthesis in pondweed?'

- **Structured inquiry:** Students are told 'how does light intensity affect the rate of photosynthesis in pondweed? Collect a lamp, a beaker, and a sprig of pondweed, and set the experiment up as in the diagram provided. Observe how many bubbles of air come from the pondweed each minute when the lamp is at 10, 20 and 30 cm distance from the pondweed. Fill in this table.'

- **Confirmation exercise:** Students are told 'the rate of photosynthesis is greater at higher light intensities. You will see this in the following experiment. Collect a lamp, a beaker, and a sprig of pondweed, and set the experiment up as in this diagram. Observe how many bubbles of air come from the pondweed each minute when the lamp is at 10, 20 and 30 cm distance from the pondweed. Fill in this table. As you can see more bubbles of air are produced when the lamp is closer to the pondweed.'

Inquiry as a continuum

The classification of inquiry-based science lessons into structured, guided or open inquiry is relatively simple to understand. However, if teachers are only introduced to this method of classifying inquiry there is the danger that they fail to see the connections between the different forms of inquiry. With this method it is difficult to see how non-inquiry lessons could be made into inquiry ones or how structured activities could be changed into open inquiry activities. The advantage of Schwab and Herron's Scale of Laboratory Openness is that it is clear that inquiry is a scale, and where you are on the scale depends on who does what in the classroom.

Maybe a better, but more complex way of looking at inquiry is to use an inquiry matrix, such as the one shown below which has been developed by Fradd et al (2002), and Sutman et al (1998). This matrix is based on the ones developed by Herron and Schwab but it splits inquiry up into more stages. Whereas in open, guided, structured method of classifying inquiry the different stages of inquiry appear to be discrete entities, in the matrix it is more obvious that inquiry occurs over a continuum. Lessons belong on a scale of 0 to 5, and can be made more or less open by changing who is responsible for certain components of the lesson. The lesson is broken down into several components, from questioning to applying, and the decisions in each of these stages is made by either the teacher or the student.

Inquiry Level	**Questioning**	**Planning**	**Implementing**	**Concluding**		**Reporting**	**Applying**
			Carrying out plan	**Analyze Data**	**Draw Conclusions**		
0	Teacher	Teacher	Teacher	Teacher	Teacher	Teacher	Teacher
1	Teacher	Teacher	Students /Teacher	Teacher	Teacher	Students	Teacher
2	Teacher	Teacher	Students	Students / Teacher	Students/ Teacher	Students	Teacher
3	Teacher	Students /Teacher	Students	Students	Students	Students	Students
4	Students/ Teacher	Students	Students	Students	Students	Students	Students
5	Students	Students	Students	Students	Students	Students	Students

The matrix makes clear that the openness of a lesson is determined by the balance between the teacher and the student's responsibilities. The more decisions that the student has to make the more open the lesson becomes. With the inquiry matrix it is easier for teachers to understand how they can make lessons more open.

2

SCIENTIFIC INQUIRY: HOW SCIENTISTS WORK

> Science is facts; just as houses are made of stones, so is science made of facts; but a pile of stones is not a house and a collection of facts is not necessarily science.
>
> Henri Poincaré

If in inquiry-based science students learn using the same methods and ideas as scientists, it is essential that any teacher wishing to teach using inquiry-based science understand what these methods and ideas are. So what is scientific inquiry? Unfortunately many people, including teachers, do not understand how science works or how science is conducted. Science is often perceived as being a mysterious secret activity, which only a restricted few made up of the very eccentric or very intelligent (and mostly male) are allowed to take part in.

If we are to encourage more people to take an interest in science it is important that they learn that science is open to everyone and is in fact very simple to do. Today's world is technology and science rich, but science also provides modern day problems, such as global warming and stem cell research. Citizens have to comprehend science if they are to make informed choices about how our world should look in the future and to fully take part in today's society (Bentley et al. 1999).

What is science made up of?

Science can be considered as containing three main facets (Koch 2000):

- The Scientific Process: Scientists use a number of skills when conducting science and these are known as the Science Process Skills. Scientists use these skills in a methodical manner, often known as the Scientific Method.

- Scientific Knowledge: The Scientific Process Skills and the Scientific Method are used by scientists to produce knowledge, ideas and concepts. These are commonly formulated as hypotheses, theories and laws.

- Scientific Attitudes and Values: Different scientists might work in different ways or believe in different things, but they still have shared values and attitudes. Science contains a number of key values.

These three things combine together to form something known as the 'nature of science.' Explained simply this is the way in which science is done and the qualities it possesses.

The Scientific Process

Science process skills

While following the 'Scientific Method' or one of the other methods of conducting science, scientists have to use a number of different skills and techniques. These skills are known generally as the 'science process skills.' It is important to remember that these skills are transferable. They are not exclusively used by scientists, but are of importance in a number of different activities unrelated to science. What makes the science process skills special is that scientists use them in a specific manner and specific sequence. The following list of process skills is one developed by the Science - A Process Approach (SAPA) program run by the American Association for the Advancement of Science (1975). They considered two kinds of process skills, the basic process skills and the integrated process skills.

The Basic Science Process Skills:

- **Observation:** Maybe the simplest but most important skill. Scientists must be able to use their senses to observe the world around them.

- **Classifying:** The grouping and ordering of objects into categories.

- **Measuring:** describing the specific dimensions of an object or event.

- **Communication:** this is the describing of an object or event that has been observed to others.

- **Inferring:** this is the drawing of a conclusion for why something occurs, based on collected data.

- **Predicting:** the making of an educated guess about some future event, based on what we have already seen.

As can be seen these skills are all related to each other and are the beginning steps of conducting a scientific investigation. Each skill merges fairly easily into the next.

The Integrated Science Process Skills:

- **Controlling variables:** being able to identify variables and then control all but one is an important part of conducting science.

- **Defining operationally:** this is the identification of the measurements to be used in the experiments. How often will you measure? What will be measured?

- **Formulating hypotheses:** this is similar to making a prediction. What is the expected outcome of the experiment?

- **Collecting data:** the gathering of information in a systematic way.

- **Interpreting of data:** the organization, analysis and interpretation of information.

- **Experimenting:** the designing of an experiment to test some hypothesis.

- **Making models:** the use of information to make a simulation of some event or observation.

These integrated skills lead on from the basic skills and as can be seen they are more complex and difficult. Because it is becoming increasingly important that students learn how to do science and not just learn facts about science it is important to teach the science process skills to students. This division into basic and integrated skills takes into account the different abilities of students at different age ranges (AAAS 1975). The primary process skills are designed to be mastered by children at the elementary of lower primary level, while the integrated skills are aimed more at children at a middle or high school level. The integrated science process skills build and develop on the primary skills. This division into primary and integrated skills reflects the Piagetian cognitive development model that will be discussed in the next chapter.

As middle or high school teachers these integrated process skills will probably be of most interest to you as these are the skills you will wish to get your students to learn. However, although the students you will be teaching will already have some mastery of the basic process skills, there is always scope for improvement. Inquiry-based science offers you the chance to get students to use a range of these skills.

The Scientific Method

When scientists work they follow a simple procedure or number of steps. This is generally known as the 'scientific method'. Generally agreed upon steps of the scientific method are:

- **Observation and Description:** The first step is to observe and describe something. Scientists tend to be good at noticing the world around them. This stage can include the keeping of notes, describing objects or processes, or even simply reading what others already know. Scientists spend a lot of time studying and reading to improve their knowledge and to learn what other scientists have already done.

- **Questioning**: After observing and describing something the scientist discovers a problem. This is normally expressed in the form of a question.

- **Hypothesis formulation**: A hypothesis is developed to explain what has been observed and described. The scientist tries to identify an answer to the question he has just formulated.

- **Predicting**: The hypothesis is then used to predict what could happen in a certain situation.

- **Experimenting**: Next an experiment is conducted to see if the predicted results are obtained. This is known as the testing of the hypothesis. Normally in an experiment variables are identified and all but one is controlled. All the variables are kept the same apart from the one being investigated. Experiments have to be replicated many times to make sure reliable results are obtained.

- **Conclusion**: The results of the experiment are used to see if they support the hypothesis. If so then the hypothesis can be accepted, if not then the hypothesis has been shown to be wrong. New problems and questions to investigate are generated at this stage.

Is there really a 'Scientific Method'?

But is there really a scientific method? Is there really a single way of creating scientific knowledge? The simple answer is no. There is no single, step-by-step method of 'doing science,' to try to produce one is an oversimplification. There are many various ways of conducting science that do not necessarily follow the steps given above.

Different kinds of scientists working in different fields work in different ways. The way a chemist works in the lab with chemicals is very different from how a geologist works in the field looking at fossils, or how a meteorologist studies the weather at the North Pole.

Even scientists working in the same field will use different steps and different methods and work in different orders. 'Lets change this and see what happens' is an equally valid, and much used way of conducting science used by scientists which does not follow the steps of the scientific method given above. Maybe it would be better if the term 'scientific methods' was used instead to encompass these different ways of working.

This does not necessarily mean that the concept and steps of the scientific method are useless. To have the term scientific method is useful because it provides a broad generalization of what scientists do and helps to explain the process of science in a simple way. It is a good starting point to start learning about science and trying to understand how science works. It creates a certain amount of order and structure, which can be a useful starting point for school learners to have. Some of the other methods of conducting science are given below. Although the methods of teaching inquiry given in this book often follow the traditional steps of the scientific method, please bear in mind that real scientists do not necessarily work in this way.

Other ways of conducting science

Experimentation is the most well known method of conducting science, but it is not the only one. The following techniques are also ways of conducting science, and were described in detail by Bentley et al. (1999).

- **Trial and Error**: Although this might seem too random to be considered scientific, it is in fact an important scientific technique. Drug and pesticides companies test hundreds of different chemicals to find ones that work. New products are often not invented but rather found through calculated luck.

- **Product testing**: Many scientists are involved in testing things to see which ones work best. Think of the safety tests different brands of cars have to go through. Many things we use every day need to be tested.

- **Inventing**: When inventing scientists use their prior knowledge, but through the process of inventing they develop new ideas. Inventing is a bit like trial and error, in that if something does not work you try something different until it does work.

- **Making Models**: Models are made to show how something works when it is not possible to do or use the real thing. They are a form of simulation. It can include the making of physical models, such as making model planes to try to see how real ones will fly when they are built. But it can also include the making of mathematical or theoretical models that show how some process works, for example how animal populations change over time when the level of food available alters.

- **Documenting**: This is simply the keeping of records, often over long periods of time. A good example is meteorologists and weathermen, who observe and document the weather to study climate change. Another example would be ecologists who document how the species present in an ecosystem change over time.

Scientific knowledge

Scientists work to produce knowledge, ideas and concepts. These are usually formulated as hypothesis, theories or laws. Many non-scientists misunderstand what exactly hypotheses, theories and laws are, and this leads them to misinterpret the importance of scientific work. For example many people denounce evolution by saying 'it is just a theory', thinking that a theory is something non-proven, purely theoretical and untested. In colloquial speech the word 'theory' is often used to mean a simple guess. How many times have you heard someone say, "Well that's my theory" when they have made a guess for why something occurred. In fact for scientists a theory is something extremely robust that all the evidence shows is correct.

A **Hypothesis** is best described as being an 'educated guess'. From looking at some object, event or occurrence scientists predict what might happen next time the same thing happens. A hypothesis is the main driver of experimentation. Scientists conduct experiment to try to show whether hypotheses are correct or not.

A **Theory** is an explanation for a certain event, which is supported by many verified hypotheses. When scientists conduct an experiment many times and continually obtain the same result, they begin to develop a theory. This is the idea for why something occurs or happens. Correct hypothesizes can be considered as being the 'evidence' for this theory.

A **Scientific law** is something that is considered as being pretty much a 'fact.' The same thing happens every time and everywhere where you try it. They are always true, and no one has shown that they are not true. Famous scientific laws include the law of gravity and the law of thermodynamics. Laws tend to be simple and specific.

There is often a false belief that there is a step like progression between hypotheses, theories and laws. For example many people believe that theories that have been 'proved' well enough become laws. Laws are seen as being 'better' or more certain than theories. This is not actually the case. Laws and theories are not interchangeable. They are simply different kinds of scientific knowledge (Bredermann et al. 2002).

While a Scientific Law is relatively simple, a theory can be quite complex and made up of many separate parts. Although separate parts of a theory can be shown to be wrong, this does not mean the theory, as a whole is incorrect. Scientists work on making the many separate parts of a theory simpler or more encompassing. Scientists generally consider both theories and scientific laws as being true. If enough evidence is collected which does not fit into a theory, the old theory can be overturned and a new one developed. However this rarely happens, and theories tend to be extremely robust.

An important feature of a hypothesis and a theory is that they must be falsifiable. It must be possible that some new discovery or results from some experiment could show that a theory is incorrect. The statement 'there are no aliens' is a scientific statement, because it will be proved wrong if aliens come to visit one day. A statement that cannot be shown to be false is not scientific it is faith.

Scientific attitudes and values

Scientists have a set of values, beliefs and attitudes which influence how they think about science and how they conduct science. Perhaps the most basic of these is the belief that the universe is understandable and the way in which it functions can be discovered. By studying natural objects scientists believe they can discover patterns, relationships and rules which help them understand how the universe functions. There is a lively debate amongst scientific philosophers and scientists about what views and attitudes scientists have. There is no agreed upon list and different authors have different ideas. The following list is taken from Smith and Sharman (1999) and includes what most scientists would consider as important attributes of science.

- **Science is empirical:** Science relies upon observation and experiment. The word empirical means to experiment, and comes from the Greek word for a test or trial, it is related to the Latin word for experiment. Scientists use their senses to collect information about the environment around them using measurement. Knowledge is built from experimentation and experience.

- **Science is tentative:** Scientists make guesses about why certain things occur. Scientists do not prove anything. Old ideas can be shown to be wrong. There are no right answers. The knowledge developed by science is therefore not rigid, but can change and be altered with time.

- **Experiments can be repeated:** The experiments conducted by one scientist can be repeated by another scientist and similar results obtained. Replication of experiments helps to confirm whether conclusions are correct or not.

- **Science is falsifiable:** Scientific claims must be testable and be able to be shown to be false. Scientists must be able to collect data that supports or refutes a claim.

- **Science is self-correcting**: Repeated experimentation leads to the discovery of errors and their correction.

Some authors also argue that science is characterized by progress, that scientific knowledge is built upon and developed over time, but this is disputed (Lakatos 1970, Popper 1972). Others consider science as being heuristic, meaning that it is based upon assumptions and hypothesis Smith and Sharman (1999).

Scientist's value open-mindedness. Although all scientists conduct research with prior views scientists try to be objective and fair in the work that they do. Scientists consider that the process of developing ideas, designing experiments and forming explanations is a creative process. Scientists also value criticism. The work done by one scientist can be criticized by another. There is no one single authority within science, even if someone is an 'expert' this does not necessarily mean they are always right and can never be shown to be wrong.

The Nature of Science

As mentioned at the beginning of this chapter the skills and methods scientists use, their ideas and knowledge, and their views and attitudes all combine to form the Nature of Science, often referred to as NOS. The Nature of Science can be considered as being the sociology of science (Ledermann et al 2002, Chiappetta, Koballa, & Collette, 1998).

However, as should have become clear while reading this chapter it is difficult to form an exact definition of the Nature of Science because there is no correct or clear single way of defining each of its separate parts. Science is complex and dynamic. Different scientists have different ways of looking and thinking about what they do. Scientists in different disciplines consider how they work in different ways and use different methods. Scientists from different cultures will look at science from different viewpoints and with different values. This does not necessarily mean that any of these views of science are wrong, only different.

It has long been recognized that it is important that students gain a good understanding of the concepts behind the Nature of Science and learn about the Nature of Science as part of their science education. The AAAS (1993) and NRC (1996) emphasize the teaching of the Nature of Science in science lessons as an important part of understanding how science is conducted and what science means. However, many students, and teachers, have a poor understanding of the Nature of Science (Abd-El-Khalick & Lederman, 2000, Duschl, 1990).

An Example of scientific research

Sexual Selection in Widowbirds

The Swedish biologist Malte Andersson (1982) studied the ecology and biology of wildlife in East Africa. One species of bird, the Widowbird, caught his attention. The Widowbird is a small species of bird that lives on the east African Savannah. It is rather dull in coloration, but is quite distinctive because the males have very long tails. These tails can be over 70 cm in length. Females have only very short tails of about 10 cm in length. Male Widowbirds live in territories, and attract females by doing a characteristic jumping dance. If a female is attracted she enters his territory and makes a nest. Successful males can have half a dozen females in their territory.

Observation and Description: Andersson observed these birds and watched their habits. From his training and prior knowledge as a biologist he thought the long tails of the male Widowbirds could be caused because of sexual selection. Sexual selection is a special branch of natural selection. Whereas in natural selection those features are selected for which are most advantageous to the individuals survival, in sexual selection traits or features that make an individual appear more attractive to the opposite sex are favored. For example in an extinct species of deer, known as the Giant Irish Elk the females preferred to mate with males who had larger antlers. Over time males with larger and larger antlers gained more mating success and antlers became larger and larger. Antlers are a useful indicator of a male deer's strength, but sometimes females will choose traits that appear disadvantageous, such as the long tails in the Widowbirds. If a male Widowbird has a very long tail but is still good enough to survive, then he must be good to mate with!

Questioning/Hypothesis formulation: Do female Widowbirds prefer to mate with males with longer tails? Andersson thought that males with longer tails would have more female mates. But how could he show this? He had to think of an experiment to see if sexual selection was really happening.

Predicting: Andersson predicted that if he extended the tails of some males they would obtain more mates than males with shorter unaltered tails.

Experimenting: He found a group of male Widowbirds and divided them into four groups. In the first group he cut the tails of the males off so that they had short tails. In the second group he stuck on the bits of tail he had cut from the first group onto their tails, meaning that their tails were now much longer than before. The third and fourth groups were control groups. The third group was left without any interference. In the fourth group he cut off the tails of the males and then stuck them on again to see if cutting the tails made any difference to mating success.

Andersson observed how successful males were both before and after the experiment by counting how many females were present within their territory. He found that males which had their tails shortened had fewer females. Males who had had their tails lengthened were able to attract more females and did better than those with the short tails. In the control groups there was no difference in the number of females present from the beginning to the end of the experiment.

Conclusion: Andersson concluded that those males with longer tails were able to attract more females and breed more than males with shorter tails: this showed that sexual selection really did happen. This experiment remains one of the classic experiments done in behavioral ecology and is a good example of how scientists work.

Meeting scientists

Susan Cartwright's work on Neutrinos

Susan Cartwright works at the department of Physics and Astronomy at the University of Sheffield, England. She conducts research into particle physics, and is studying the properties of neutrinos, these are weakly interacting, almost massless particles produced in radioactive decay and other similar processes. Learning about these will help us understand why our universe is the way it is.

Author: How do you do your research?
SC: I work as part of a large international collaboration, with several hundred scientists from many countries including Japan, Korea, the USA, and Canada. We hope to send a beam of neutrinos generated on the east coast of Japan, not far from Tokyo, to a detector located under a mountain on Japan's west coast, a distance of 295 km. This detector already exists, but needs to be complemented by a "near detector" located close to the origin of the Beam. I am helping design and build this near detector. This work uses a very large set of C++ computer programs.

Author: How important is answering questions to you?
SC: All scientific research is "answering questions," though the questions range from the apparently trivial ("what is the melting point of this substance?") to the profound ("what is the geometry of the universe?"). I can't imagine a scientific research project that wasn't "answering questions" in this broad sense.

Author: What do you think makes a good scientist?
SC: Science is about answering questions. Scientists need to be able to pick good questions: at any given time in any given field, many lines of inquiry are open, and some will be much more fruitful than others. Really great scientists seem to have the ability to identify the fruitful ones.

Scientists also need curiosity about the world. Scientists need a constructively critical outlook; new results need to be subjected to adequate scrutiny. Patience is also important: Rome wasn't built in a day, and neither is the average experiment (our beam won't turn on until 2009, and we are very worried that we won't get the experiment finished in time).

Author: How did you get interested in science?
SC: I can't remember a time when I wasn't interested in science.

Author: What skills do you think it is important for scientists to have?
SC: Almost all scientists require good communications skills, both oral and written. It is essential to be able to write well. Most results are first reported orally at international conferences, so good oral presentation skills are also needed.

Most scientists require good IT skills. Particle physics is particularly computer-intensive. The physical sciences typically require high levels of mathematical Skill. Good knowledge of electronics is almost always useful in the physical sciences.

Author: Why is science rewarding?
SC: For the same reason that being a writer or artist is rewarding: It's a creative art. When you build an experiment or complete an analysis, you have created something unique and personal, even though a C++ program may not be a particularly aesthetically pleasing object!

A successful experiment increases our understanding of the world. Science is intellectually engaging - you get to use your knowledge and skills to develop something you can call your own.

Kim Worley's work on the Human Genome Project

Kim Worley is an Associate Professor working at the Human Genome Sequencing Center, in the Department of Molecular and Human Genetics, Baylor College of Medicine, Houston.

Author: What are you conducting research into?
KM: My area of supervision is bioinformatics, particularly genome assemblies. That is working with computers to analyze DNA sequence and features. We assemble genomes by evaluating the short (500 to 1,000 base pairs) sequences generated by the sequencing process in the lab for runs of identity that indicate that the pieces overlap and by using information about the relationship between two short pieces of sequence that were sequenced from the two ends of a single subclone.

Author: What do you hope to find out?
KM: Ultimately, we hope that our research will provide information about human health, disease, and biology. The genome sequence of organisms other than humans informs human biology, because sequences that are conserved between species over evolutionary time are important for their function.

Author: How do you do your research?
KM: We do a lot of sequence comparisons, using tools like BLAST and Crossmatch. We manipulate large numbers of sequence files (>38 million for the bovine assembly), and the large files with information about the sequence files.

Author: Do you try to answer 'questions' in your research?
KM: Our research primarily produces data that speeds the research of many other folks around the world. Researchers on a particular disease or gene can make years of progress in a week once genome sequence becomes available.

Author: Do you use the 'scientific method' when sequencing DNA?
KM: Yes and no. We try to understand how to improve genome sequencing and assembly - many of the questions there are hypothesis driven. But, our primary goal of sequencing many organisms is less hypothesis driven.

Author: What do you think makes a good scientist?
KM: A questioning mind, the will to follow through, and an ability to communicate.

Author: Is science cooperative?
KM: Absolutely. Large projects like ours require collaborations of many people here (200 in our lab), and researchers around the world to interpret the data.

Author: What skills do you use when doing research?
KM: Different types of science require different skills. The more skills you have the more you can bring different approaches to a problem to gain new insight. My experience in engineering gives me a different perspective on problems than people who trained in biology. People who work with yeast can approach different questions than people who work with human cancers, but they can combine their knowledge and gain insight into both.

Author: Why is science rewarding?
KM: Unlike many professions where image or spin is important, science is testable. In that way it approaches truth.

Author: How do you learn while doing science?
KM: By reading, talking with others, and experimenting.

Author: How did you learn to do science?
KM: By working with other scientists.

3

CONSTRUCTIVISM: HOW CHILDREN LEARN

A teacher is one who makes himself progressively unnecessary.

Thomas Carruthers

At school were you ever taught how to learn? Or were you just expected to turn up and remember what the teacher said? A teacher's job is to get his or her students to learn. To be able to do this it is essential that teachers have a good understanding of how their students learn.

The Behaviorist view of learning

The method in which you were taught at school probably reflected a theory of learning known as behaviorism. The behaviorist view of learning was originated by the American psychologist J. B. Watson, and extended by B.F. Skinner. Behaviorists believe that learning has little to do with psychological changes, but instead learning is a behavioral change. When something is learnt the behavior of the individual alters and this change can be measured or observed in some way.

A key feature of Behaviorism is the theory of 'operant conditioning', which says that the reason we do something depended on the consequences of us doing that action in the past. If students are praised when they do well and complete some task correctly, when they have to do the task again in the future they will remember how to do the task and successfully complete it.

The idea of operant conditioning has important implications for how behaviorists believe people learn. Learning using behaviorist ideas emphasizes rote and drill learning where learning is repeated time and time again until the students can do or remember something. A typical example of an exercise promoting this idea of learning would be a student learning a foreign language by having to complete a text with gaps in it. When they have completed the task successfully they have learnt what is needed and achieved the goals of the lesson.

The Constructivist theory of learning

Over the past century a new theory of how people learn has been developed. This is known as the Constructivist theory of learning. Key features of Constructivism are:

- **Prior knowledge: Learners already have ideas and knowledge before they begin to learn:** A key difference between Constructivism and earlier theories of learning is that Constructivism acknowledges that learners begin the learning process with ideas and knowledge of their own. In Constructivism this prior knowledge is acknowledged and used as a base on which to construct further knowledge. Learners may also have 'misconceptions,' or incorrect ideas, and in Constructivism it is important that these misconceptions are recognized and then altered through the learning process.

- **Knowledge is constructed:** The key feature of Constructivism is that learners create their own ideas. Ideas and knowledge are not simply 'passed on' from teacher to student, instead each student has to create, construct or build their own understanding. The ideas that learners create fit onto their previous ideas. If new ideas will not fit with the learners previous ideas cognitive conflict occurs and the learner must change their preconceptions.

- **Learning is active:** Students actively construct knowledge as they learn. Active learning is promoted when students have to do something themselves, rather than simply being told what they need to know. Students learn best when they are engaged in concrete hands-on learning. Learners need to be able to do, to touch, to make, to discover.

- **Learning depends on the environment the learner is in:** Learning depends on both the social environment and the physical environment of the learner. Learning is a social activity. Students learn best when they see the relevance of what they are learning. What students learn must have some connection to the world in which they live and the things that they do everyday.

The Constructivist theory of learning has important implications for how teachers help their students to learn. If these points are considered carefully it will be seen that they result in a different role for the teacher than that which is traditionally perceived. Normally teachers are seen as being a 'passer on' of knowledge. Students enter the classroom to be given knowledge by the teacher. A 'good' teacher is one who knows a lot about his or her subject.

Teachers in a constructivist setting instead of 'teaching,' have to get their students to learn themselves and construct knowledge independently. They have to find ways to get students to learn actively in a hands-on way. A teacher in such a setting is more of a mentor than a teacher. Teachers do not need to know about the topic being explored, instead it is more important that they are able to animate students to ask questions which are suitable for research, reflect on the experimental design, and decide whether data has been collected and analyzed in a suitable way. Teachers cannot be experts on every topic, and do not need to be to teach in an open or inquiry manner. The teacher and the students explore a topic together.

We all try to build up ideas and understanding to explain the things around us. Sometimes we are right in our ideas, but sometimes we are not. Children are no exceptions to this, they also try to think of reasons for the things they see, and these ideas can also be false. Education specialists call these false ideas 'misconceptions.' Consider this following example from Harlen (2004):

"The teacher explained the appearance of dew on grass on a cold morning in terms of water vapor in the air. The girl already had an explanation for this; her own idea that the coldness of the grass created the water. This idea also fitted her experience of the water drops on a bottle just after it was taken from the fridge. "

One of the goals of the teacher is to find out which misconceptions their students have, and to try to correct them. However this can be difficult. A child will retain his or her ideas; if they believe that they make better sense than the explanations they are given by the teacher (Harlen 2004). Children may remember explanations given to them by their teacher but have no real understanding of them, and thus may cling to their own misconceptions. Learners can be extremely reluctant to change misconceptions (Carin et al. 2005).

The process where a student is confronted with evidence that contradicts misconceptions and has to decide on a new explanation is known as conceptual change. For conceptual change to occur students have to become dissatisfied with their expositing idea, and the new idea must be more plausible and understandable. Teachers need to challenge students to consider different explanations and to discard misconceptions (Carin et al. 2005). Conceptual change is an important part of cognitive development.

A 'traditional' and Constructivist classroom compared

The best way to show the difference between a constructivist and 'traditional' classroom is to actually give examples of teachers teaching in these different ways.

As part of a course about how to teach inquiry Julie, one of our student teachers, had to give a sample lesson to a small class of middle school students. She had decided to teach about how mice learn to use mazes. She taught in what could be described as being a very 'traditional' way, even though we did not want her to. She stood at the front of the class, and dominated the lesson. She began by lecturing the students about mice biology and behavior, introducing such concepts as operant learning and trial and error and writing important words on the board. The students sat in rows and listened, seemingly attentively.

Next the students were allowed to do practical work. Real, live mice were available for use as was a maze made out of toy building blocks. The idea was that the students would see that the mice learnt by trial and error to find there way out of the maze. The students were carefully instructed how to put the mice in the maze and what they had to observe. After the students had done this they were told to write what they had found as an experimental write up in their lab books. Unfortunately the practical was not very successful. Mice maybe are not the most cooperative of lab animals! The students were disappointed. 'We didn't get the right answer!'

Although Julie thought she was teaching in a constructivist way, she was in fact not. She had provided the students with information at the beginning of the lesson, and then tried to get them confirm this by getting them to conduct an experiment. She decided on which method to use, not the students. The students own questions caused problems for Julie; she had only prepared what she wanted them to learn. Students asked questions like 'What sex are the mice?' 'How can you tell?' 'Do mice like water?' 'Do mice smell the way round the maze?' To these questions Julie had no answer and became embarrassed, and simply tried to divert the students onto another question, or told them that was not what they were meant to be studying! Maybe a more experienced teacher would have said 'I don't know, lets try to find out!'

Sarah, however did things very differently and in a much more constructivist way when she had to teach a similar class. She decided that she wanted to teach the class about the sense of taste. Unlike Julie she started the class differently, although the students instinctively sat in rows as they came into class, she moved from the front to be actually in the middle of the students. Instead of simply lecturing, she began by eating a banana, and then asking the class 'Why does a banana taste like a banana? Why does it not taste of something else?' This became the focus for a small class discussion, in which Sarah simply asked questions and let students express what ideas they had.

The practical example Sarah used was more inquiry-based than the one used by Julie. Sarah provided the students with an investigation question to start them off; 'What effect does your sense of smell have on your sense of taste?' The students then had to develop a way of answering this problem themselves. Sarah, prompted the class by asking them questions like, 'What do you think will happen when you can't smell?' 'Why?' 'Have you ever actually tested that?' 'How could you do that?' The students were responsible for designing the experiment themselves, and at the end, they told Sarah what they had found. The students set up an experiment where one student was blindfolded and then fed different types of food. They had to guess what food it was. Next, the student had a peg put on their nose, and had to re-taste everything and guess again. The students found that it was more difficult to guess when you had a peg on your nose. Not an ideal experiment, but at least student designed! Once the students had given their findings, Sarah gave the students a short worksheet with further information and questions for homework. As the students read this, one exclaimed 'I know all this, we have just learnt it!' In comparison to Julie's lesson the information came at the end and not at the beginning.

These examples show the main difference in the classroom when you follow constructivist ideas. Basically in a constructivist classroom and a traditional classroom you have different aims. The aim of a constructivist classroom is that students understand. In a traditional classroom the main aim is that students collect as much information as possible. This difference in aim leads to different ways of dealing with the curriculum and organizing lessons.

Traditionally based lessons tend to stick rigidly to the curriculum or teaching plan. Julie had a meticulous lesson plan, which was well planned, and conscientiously made, but it fell to pieces because it tried to teach too much and did not consider students desire to answer different questions. Julie simply wanted to teach her facts. This is in line with many traditional curricula, which want to cover as many different topic areas as possible to allow students to obtain the broadest possible knowledge possible and to learn the most important facts in every area.

Constructivist teachers consider the learning of facts as a secondary aim. Facts can be found simply from looking in a book. Sarah concentrated on getting students to understand a relatively small idea; that your nose plays a large role in your sense of taste. She could have taught this single piece of information very quickly, simply by telling students. But instead she wanted them to understand what it meant and to experience it for themselves. This takes more time. It is better to teach a few topics well than many poorly. A teacher with a constructivist background will be willing to leave the curriculum if it is necessary to allow more time for students to understand. Sarah, like Julie, had also been conscientious about developing a strict lesson plan, but she was more relaxed in the classroom, and was happy to 'let the lesson plan go' and let the lesson simply roll along. Sarah's plan was more general, while Julie's specified almost what she should be doing in every minute.

As mentioned above one of the key points of constructivism is that learning is more successful in a group environment. Julie's classroom did not encourage group work. As in many conventional classrooms the students sit in rows facing the teacher, and thus cannot interact easily with other students. This fits in with the behaviorist view that learning is individual. To promote constructivist learning students should be asked to sit or work in small groups where they can easily talk and work together. Sarah tried to do this by placing herself in the middle of the class. For work that involves the whole class students should sit either in a circle or in a 'U' shape, so that everyone is 'at the front' and that everyone can participate equally.

One thing not considered in our example is assessment. Again there are big differences between traditional and constructivist classes. In a traditional class after being taught a specific topic, students are expected to demonstrate their knowledge and understanding of this topic. Students would typically answer questions from a textbook or write out a lab report. In constructivism however, assessment is interwoven throughout the entire lesson, and is not simply seen as the final activity of the lesson. There are a number of reasons for this. Firstly constructivism emphasizes the prior knowledge of the students. Before a teacher can begin the lesson they have to find out what the students already know about a topic. How and what the teacher teaches should depend on what the students already know. Teachers need to know at what stage the students are at, what misconceptions they have, and what ideas they already possess. A second reason for assessment to be interwoven throughout the lesson in constructivism is that it is also important to find out how well students are at the process skills of science. In traditional lesson how well the student's work like scientists is not important, but in constructivism it takes on more importance.

The way in which Julie and Sarah interacted with their classes was very different. Julie saw herself as the 'teacher', the ones with the knowledge, who was responsible for passing information onto the students. Sarah, however, did not really 'teach' the class anything! She started a class discussion in which they gave their own ideas. She was kinds of mediator, helping the students develop an experiment on their own, and simply used probing questions to direct them. In a constructivist classroom the student is not an 'empty vessel' into which the teacher has to pour information, students are capable of independent thought and of developing ideas for themselves. Students have to be teased and coaxed to form new ideas and ways of thinking, and that can only be done by asking them leading questions, showing them unexpected events, and by letting them work for themselves.