Learning to Teach Inquiry: A Course in Inquiry-Based Science for Future Primary School Teachers

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Abstract: We developed a course in inquiry-based science for students training to become primary school teachers. The emphasis of the course was teaching students to do inquiry-based science activities themselves, as this is the best way of learning how to teach using inquiry-based methods.

Keywords: Inquiry-based science, teacher education, college science, biology, open learning.

Introduction

Documents such as the National Science Education Standards (NRC, 1996) and the Benchmarks for Science Literacy (AAAS, 1993) emphasize the importance of teaching science through inquiry. Despite these recommendations inquiry-based science is not widely used as a method for the teaching of science in schools. One of the possible reasons for this are the teachers responsible for its use in the classroom (Keys & Bryan,2001). Teachers may have little experience of conducting inquiry-based investigations themselves and therefore have little understanding about what inquiry involves and how it can be taught.

We decided to tackle this problem by developing a course in inquiry-based science for students training to become primary school teachers. The emphasis of the course is in increasing student's own personal experience of inquiry-based science. The course contains a number of varied and interesting inquiry-based activities in which students are expected to participate and complete (TABLE 1). We feel that these activities more effectively teach students about inquiry than traditional lecturing.

While completing these inquiry-based activities students gained practice in using science process skills, and gained an understanding of how scientific investigations are conducted. The unique structure of the course means it could easily be adapted to teach scientific investigation skills to students from a variety of scientific disciplines and not only those planning a teaching career.

TABLE 1. Summary of course structure.

Session	**Activity**
1	Fish Behavior *
2	Lectured Lesson: Inquiry-based design
3	Designing an inquiry-based lesson; presentation of group ideas. How big is a water drop? *
4	Snail racing * Egg Drop Challenge *
5	Lectured lesson: Open Learning
6	How does a candle burn? *

TABLE 1. cont.'d.

7 + 8	Designing and planning of an inquiry-based science lesson.
9	Teaching of designed lessons to groups of 3 to 5 schoolchildren.
10	Evaluation of taught lessons and course summary .

*Inquiry-based activity.

Fishy beginnings

The course begins with a simple observation experiment. In groups of three, students were asked to observe a fish tank which contained either a Dwarf Shell Dweller Cichlid (*Lamprologus ocellatus*) or a Siamese Fighting Fish (*Betta splendens*) and to investigate how each behaved. Students could use a variety of materials, including shells and brightly colored paper, but were not told what to do with these materials or what they should try to find out. The aim of this activity is to introduce students to more open methods of learning. Most students beginning the course are used to doing very structured experiments during science lessons, and expect to receive a list of instructions and be told what results they should expect to find.

Many of the students given this activity are at first perplexed. 'What do we have to do?' 'What are we supposed to find?' were common questions. However, after some time some students started to experiment without being directed. Some placed shells in the fish tanks and observed how the fish swam into them for protection. Others stuck pieces of colored paper onto the side of the fish tank to see what reactions it caused in the fish. Some students began cutting the card into fish shapes and then seeing how the fish reacted to different sizes and colors of cardboard fish. Not everything seemed to work and this worried some students.

The practical work took some time, mainly because of the hesitancy of the students in deciding themselves what to do. At the end of the experiment the idea that in inquiry-based teaching the student decides what to study, what to do, and what the answers mean were discussed. This activity has proved to be a good introduction to open methods of teaching for students.

What is inquiry-based science?

The second session was purely lecture based and introduced the theoretical background of inquiry-based science. Students learned what inquiry-based science was, its characteristics, and its development. They were told that inquiry-based science is an open student centered teaching technique. The different types of inquiry-based science; open, guided or structured, were also discussed. To reinforce the ideas taught in this session students had to design a simple inquiry-based experimental lesson for homework.

Designing a simple experimental lesson

A good way to find out if students understand what inquiry-based science teaching involves is to ask them to plan an inquiry-based lesson. Groups of students were given a set title and had to use this to develop a suitable inquiry lesson. The lesson plans had to include some kind of practical experiment or investigation, which the schoolchildren themselves design or plan. The themes which the students are given included; dandelion growth, microscopy of human hairs, housefly anatomy, woodlice behavior, and nettle stinging.

Each group presented their ideas to the class in the third session after having a week of preparation time. Ideas were varied. For example, the group tasked with designing a lesson about dandelion growth developed a lesson in which schoolchildren would compare dandelion growth in sunny and shady areas. The group given the title 'woodlice' planned a lesson that contained an experiment where schoolchildren would study whether woodlice preferred diet or regular cola. The housefly group planned a lesson in which schoolchildren would study and draw houseflies with hand lenses and look for differences and similarities.

Each group's ideas were commented on in a class discussion. This proved useful in evaluating and assessing the ideas given. When, for example, one group presented a lesson plan that included no inquiry-based or experimental element, but instead research on the Internet to answer some teacher decided question, the other students were quick to point out that this was not inquiry-based science.

How big is a water droplet?

This activity makes students think about how investigations should be conducted and allows them to practice their inquiry-based skills. Students are simply asked to find the answer to the single question; "How big is a water droplet?" Students are provided with a beaker, water, pipettes, and paper towels. Although this seems a relatively easy question to answer, once you begin studying how water drips, and the different factors which affect the size of a water droplet, you begin to realize it is much more difficult to answer than you first thought.

There are a surprising number of possible variables that could affect the size of water drops coming from a pipette. When asked students suggested that the height from which water is dripped the size of the aperture of the pipette, the properties of the water, and the surface on which the water is dripped could all have an affect on the final size of a water droplet. They were then prompted to carry out experiments to find out how big a water droplet is, and whether these suggested variables did in fact affect the droplet size.

Some of our students tried weighing droplets from pipettes of different sizes, to see if this affected the size of the water droplet produced. Another group tried adding oil and soap to the water to see if this would affect the water tension and thus the size of droplet produced. One group tried dripping water at different angles from the pipettes. Some groups measured the diameter of the droplets produced as they landed on a non-absorbent workbench, while others measured the size of stain left by a droplet of water on a paper towel. One group counted and collected a large number of water droplets in a scaled beaker, and then divided the total volume of water they had by the number of droplets they had collected to find the size of a single droplet. The fact that there is no correct answer to this problem mirrors many problems in real life science. This exercise can be used as an introduction to a discussion about variables in experiments, how experiments can be made 'fair,' and overall experimental design.

Snail Racing

Another good example of an inquiry-based exercise used in the course was snail racing. Students were asked to bring one or more living snails to class and a 'snail-attracting object' of their choice. Students brought a variety of different things they thought would attract snails, including dandelion leaves, grass, salad, sugary fizzy pop, and even a bottle of beer. In class students were then given the question "How can you make your snail travel fastest?"

Students went about answering this question in different ways. Some students used the various snail-attracting objects to see to which ones snails were really attracted and if it affected the speed at which they traveled. Some other students compared the speed at which snails moved over different surfaces, for example work bench surfaces, newspaper, and plastic sheeting. Some groups set up a 'start line' and 'finish line' and raced their snails from one to the other. Another group, being more exact, timed the distance snails moved in 5 minutes.

Students were not told how to conduct the snail races or how they should find out what affected the speed at which snails traveled. They had to work out ways of finding out these things themselves. Students themselves have to find the solution to problems they encounter. One such problem is that snails rarely travel in a straight line, and sometimes go in totally the wrong direction to that desired. One group decided to 'disqualify' snails that traveled in the wrong direction, while another group ingeniously used pieces of string to measure the exact distance snails traveled regardless of direction. Although different groups might use different methods, this does not necessarily mean one method is better or worse than another, each is valid in its own way.

The Egg Drop Challenge

Students were then challenged to design a way in which eggs can be dropped from a great height without being broken. Only simple materials such as newspaper, sticky tape, towels, cardboard, plastic bags and string were made available, although groups could improvise or use other materials.

Each group came up with a different solution to this problem. One group surrounded its egg with towels and cloth, so that when the egg landed it would be sufficiently cushioned from the ground. Another group designed a parachute like contraption so that the egg would float to the ground. Another group suspended their egg with string in a box, so that the strings would act as shock absorbers and absorb the jolt when the box landed on the ground. One group inflated plastic bags around the egg as a sort of air cushion. This activity caused a lot of activity and interest. Some groups named their eggs and added faces.

Once each group had finished their designs it was time to test them. One member from each group went to a high third story window; everyone else went outside to watch the eggs land. Each egg holder was dropped from the window onto a specified target. Afterwards all the eggs were examined for damage. The group who emerged with an undamaged egg and who had been closest to the target were declared the winners.

Open Learning

After completing a few experiments, we felt that it was important that students heard from teachers who had experience of teaching using inquiry-based methods. One morning the students visited a local school to talk to a teacher who specialized in open teaching techniques as proposed by the German science education specialist Martin Wagenschein (1968). The students heard about the teacher's experiences and ideas, and were shown how one simple lesson could be transformed to make it more open-ended by letting schoolchildren make the choices and decisions in the classroom instead of the teacher. The teacher emphasized the importance of getting schoolchildren to be active and involved during lessons, and the importance of teacher questioning in promoting schoolchildren to think for them self.

How does a candle burn?

One good example of open teaching is the study of how candles burn (Theophel, 1995). To start this practical activity students were given the question 'How does a candle work? Students were given candles, asked to light them, and then asked to observe and draw a candle flame. A class discussion followed where students described a candle flame. During the discussion the tutor gave the class no direction or information, but used questioning to make students observe the candles more closely and to describe what they saw. Can you see anything else? What about the wick? What about the wax? Although students started out with rather simple descriptions, by this questioning a more detailed description began to be drawn out.

One student observation was 'as the candle burns it gets shorter.' This prompted the question and problem 'Where does the wax go to?' from the tutor. The students were unable to answer this definitively. The tutor suggested some experiments. First the students were instructed to blow their candles out, 'What did you see?' There were sometimes plumes of white smoke, and the students concluded this was wax steam leaving the candle, and that this was what burnt in the candle flame.

Next the tutor suggested that students, with the use of tongs, place a slide over the flame. Students observed that black soot collected on the slides in large patches. The tutor then prompted students to place a slide actually into the center of the flame. Soot collected in a ring shape, with the center of the ring which had been held in the middle of the flame being clear of soot. The students thus concluded that smoke is only produced at the outside of the flame, and not in the middle. One student thought this was because the center of the flame was the hottest and that the soot was simply burnt away without collecting on the slide.

The tutor suggested an experiment using wooden splints, by placing a splint for only a split second in the flame you can see where the wood begins to burn and is hottest. This took some practice, but the students began to see that the wood that was in the outer parts of the flame burned, while that which had been in the center was not burnt; therefore the center of the flame is cooler than the outer part. The tutor then explained that in a candle flame the outside burns hotter because there is more oxygen available to the flame; in the center of the flame there is not as much oxygen and it does not burn as well.

The aim of the practical was to show students that often things that seem simple can be quite complex, and that a good teacher instead of telling students the answer, prompts students with good questions to see, observe, and think of the answers for themselves.

Designing and teaching an inquiry-based lesson

For the final sessions of the course, students worked in groups of three to plan and then teach an inquiry-based science lesson of their own design to a small group of 14 year old students. As the students in our course were training to become teachers, it was important that they gained real first hand experience of teaching in an inquiry way. By having to plan and teach an inquiry lesson themselves the ideas the students had learned throughout the course were reinforced.

Two sessions were set aside to allow students to find an idea and then plan and design their lessons. Members of the staff were in attendance to provide useful suggestions or help if difficulties arose. Students were free to use the sessions how they wished. Some groups used the time to research ideas in the library or on the Internet, other groups used the time as 'group meeting time' to discuss the work they had done individually over the last week, while some groups tried out and practiced experiments they thought they could use.

In week nine a class of 14-year-old school students visited the university and were divided into small groups. Students were allocated a group of schoolchildren that they had to teach in an inquiry-based way for an hour. The schoolchildren were eager to participate in an interesting diversion from normal lessons. This exercise proved extremely useful for the students as it allowed them to confront some of the difficulties with inquiry-based science teaching. A variety of different ideas for inquiry-based lessons were taught, including 'the behavior of stick-insects,' 'can mice follow mazes?' and 'which parts of the tongue taste can taste what?'

The final session was a summary session. First the teaching from the previous week was discussed and evaluated as part of a class discussion, and this was followed up with a discussion about the course in general with final thoughts from the tutors and students.

Anecdotal comments from students about the course are positive. Students comment that they enjoy actually 'doing something' as opposed to simply listening as in traditional lecture courses. Students find the practical activities especially interesting as they are something they can actually use themselves in the classroom when they are practicing teachers. Because the students do the practical work themselves, they feel they better understand what inquiry-based science is, and how they could teach it themselves. Students were given questionnaires which asked what views they had about inquiry-based and open teaching both at the beginning and end of the course. The results indicated that students would be more willing to incorporate aspects of inquiry into science lessons when they became teachers after they had taken the course.

Conclusion

The course outlined here has proved to be an effective way of introducing prospective science teachers to inquiry-based science. The structure shown here can be used as a template for other similar courses, or could be adapted for courses teaching students scientific investigation skills.

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