The "First" Artificial Diamond

In 1893, the French chemist Henri Moissan announced success where others had repeatedly failed. He had apparently produced the world's first artificial diamond. The method involved subjecting graphite to high temperature and pressure, and the resulting diamond was flawless and nearly 1 mm in diameter.

However, the result was mystifying, because nobody was able to repeat the feat. In fact, we now know that his method could not have worked anyway. Far greater temperature and pressure are required.

It turned out that an assistant had decided to "help" by planting his own diamond as a prank. Unfortunately, the prank was allowed to go too far, to the extent that owning up to the hoax became considered to be no longer an option. The loss of a valuable diamond must surely have contributed to the lesson learned by this prankster!

Curriculum Reform in Science: Getting Started

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Abstract

In spite of the almost universal call for curriculum reform in science education that began over a decade ago, research indicates that very little change is actually happening in a large majority of schools. Perhaps the reason is that teachers need to see a relatively fast, easy way to get started. This article considers some desirable elements of reform and the role that open-ended investigations might play.

For the past 10 years, many researchers in science education have been calling for change leading to improvement (Anderson, 1995; Anderson et al., 1994; Fensham, Gunstone, & White, 1994; Van Den Akker, 1998; Yager, 1991). Various studies in the USA, UK, and the rest of the world report "an awareness of poor student outcomes in science" (Van Den Akker, 1998, p. 427), indicating that teachers recognise the need for reform. However, the same study goes on to report a "huge gap between improvement ideals in various reform efforts and current classroom practices" (p. 438). The change questions most frequently raised concern first, what should be taught if students are to develop scientific literacy, and second, how the determined programs should be implemented. Overall, I believe, there are two main areas of change required:

1. increased student centredness (or a focus on outcomes or student understanding, as opposed to a focus on content), and

2. trimming down the over-crowded curriculum, in order to maximise understanding.

Student Centred? Doesn't That Mean No Class Control?!!!!

The traditional view of teaching and learning has focused on what is being taught, the content of the lesson. We as teachers have believed that our role is to impart new information, and if students are paying attention or are motivated, they will learn what has been taught. In other words, we have believed that learning is the result of teaching.

Constructivist Learning Theory (Cheek, 1992; Yager, 1991) maintains that learning is not the result of teaching only. Rather, it is the result of what the student does with the new information he/she is presented with. In other words, students are active learners who construct their own knowledge, and not passive recipients of new information, somewhat like a sponge. This theory is the basis of the shift away from a content-focused pedagogy towards a focus on student outcomes or understandings, with some countries describing the outcomes in terms of standards.

Many teachers see this learning theory as just a new way of presenting what we already know: "Okay, doesn't that mean the same as above, that students will construct new knowledge as the result of our teaching, as long as they are motivated or paying attention?" The answer is no. While being motivated and paying attention to our delivery is of course a factor in learning, there is something even more important to be considered, and that is what students already know and bring with them to each new learning experience.

Since Constructivist Learning Theory asserts that students construct their own learning based on what they already know, the ideas they bring with them to the classroom have a profound effect on what they actually learn there. Teachers need to recognise this prior knowledge, appreciating that it will be either a bridge or a barrier to new learning. Where prior knowledge is in fact at odds with what experts currently believe to be true (i.e., where students have alternative conceptions, or misconceptions), teachers need to employ teaching strategies that present the students with conflict between the incorrect knowledge they have and the new information being presented. In this way, students can identify the differences between the two and are given opportunities to construct their own correct concepts so that new learning can occur. Collaborative discourse is one suggested strategy for achieving conceptual change where misconceptions exist in the minds of learners. Cooperative group work on concept-focused tasks, a constructivist teaching strategy, has been found to have a significant effect in helping students overcome misconceptions (Basili & Sanford, 1991).

A student-centred style of learning is therefore the first major focus for change stemming from the constructivist teaching reform. Here, the strategy of teacher as information transmitter with a "chalk and talk" or lecture approach is minimised in favour of the teacher acting as a facilitator, where students "drive" the lessons in order that they will actively construct their own knowledge. Teachers should concentrate not on whether or not they have taught something, but on whether or not the students understand any new information. This does not mean, though, that there is no direct teaching. Some direct inputs are necessary for outcomes to occur. The suggestion is merely that teachers should move away from a predominantly "chalk and talk" teaching style. In a constructivist setting, "activities are student-centered and students are encouraged to ask their own questions, carry out their own experiments, make their own analogies and come to their own conclusions" (Hanley, 1994).

The second change emphasis, trimming the curriculum, emanates from the first. In other words, a starting point in making lessons more student-centred is to reduce the content, since constructivist teaching methods are generally more time-consuming than traditional methods. In many countries, science teachers are being asked to cut back on content in order to maximise opportunities for students to construct their own knowledge, in conjunction with understanding. The emphasis is firmly on the idea that "less is more". Teachers are required to focus in depth in their treatment of major concepts, rather than covering lots and lots of facts and concepts in minute detail. In this way, we can focus more on what our students are actually learning, rather than on time and deadline aspects that have often in the past dictated our teaching strategies.

You Can't do That to the Curriculum!

Blasphemy! We can't possibly leave out the topics we have taught our students since we began teaching! The idea of students passing into post-compulsory chemistry courses without having learned the mole concept is preposterous! Physics students will most definitely need to have done energy calculations before they enter the post-compulsory course! To many, the idea of attacking science content is almost sac religious, like pruning books of the bible, or leaving some books of it out altogether, would be to a religious person!

However, for the sake of appearing progressive and not impossibly conservative, we will agree to look at the idea, and sit around the staff office table with a notion to lightly "prune" the syllabus. Half an hour later, and after much loud and undisciplined debate, we have all failed to agree on any one topic that can be removed. The physical science teachers have, of course, agreed that much of the biological science topics may be removed, and the biological science teachers have unanimously agreed on the scrapping of most of the physical science topics, but no overall consensus has been reached.

Teachers who use traditional pedagogies, as well as more progressive teachers (and not just of science), are very big on pre-requisite learning. Anderson (1995) reports that “the notion of preparing for the next level of schooling …. is so deeply ingrained in the culture of schools that to omit any topic they know will be encountered later makes teachers feel inadequate” (p. 34).

Contrary to popular belief, post-compulsory school students need to have very little pre-requisite factual knowledge. Very little of what is learnt prior to this level is retained anyway (ask any post compulsory teacher!). Students who fail to understand difficult concepts construct incorrect meanings which act as barriers to future understanding which are very difficult to shift by traditional teaching methods (Sewell, 2002). Teachers who use predominantly traditional pedagogies have often failed to take into account the current research that indicates the potentially damaging effect that misconceptions (or wrongly learnt information) can have on student learning of the more difficult concepts. It would be arguably better for many students not to have encountered many concepts at all prior to post-compulsory instruction in them. Re-teaching, to overcome student misconceptions, before new real learning with understanding can occur is much more time-consuming than the education process where students begin with knowing nothing at all about a new concept. Pre-requisite instruction can actually hinder the learning process.

The argument for the inclusion of units of content in a subject purely on the basis that such content has always been “taught” to students of compulsory school age is no longer valid (if it ever was) in the light of current accepted learning theory. Curricula need to be thoroughly audited in light of the fact that in our world of rapidly changing and continually superceded factual information, there is not a lot of information that students need to know. However, there is an awful lot that students increasingly need to know how to do.

Rather than beginning this somewhat daunting task from scratch, though, help is available in pruning the curriculum. Please visit AAAS Project 2061 (2002), “Excerpts From” (2002), “Less is More” (2002), and/or “Benchmarks On-Line” (n.d.) and find out how the American Academy of Science went about the process, and what resources are available to help teachers in this task. Pruning the curriculum is no easy task. Indeed it may take several years to successfully work through the process. Outside agencies and organisations may need to be consulted and worked with before a consensus can be reached. But ultimately the resulting science program will allow more time for student learning, where meaningful learning is the goal.

Reform: A Daunting Task

The pressure to move towards a minimalist approach, or one that focuses on essential concepts, and the shift to student-centredness by teaching systems, is quite daunting to many science teachers, who believe they are faced with the prospect of total disruption to the "business as usual" style they have survived on in the classroom for many years. The new approaches to learning are "a formidable challenge to teachers [as] … to achieve [them] … teachers will have to change almost every aspect of their professional equipment" (Black & Atkin, 1996, p. 63).

With research from the past decade resulting in awareness of poor student learning outcomes in science, many teachers agree in principle with the constructivist approach to learning and can see the need for reform or change. However, as mentioned above, the reform is in many cases not happening. The various worldwide studies reported by Van Den Akker (1998) report the "persistency of traditional teaching practices" (p. 432). The reason is not apathy, or lack of funding, as many commonly believe. I believe that many teachers quite simply don't know how and where to start.

I also believe another difficulty for many of us, as teachers, is not in adapting to different strategies but in shifting our thinking! We often see change as being a threat to our complacency. We are happy with what we're doing and don't want to move out of our "comfort zones." "Besides, it will take lots of time and that's something I don't have," we might say. However, if we can accept that change is desirable (have you considered the possibility that many students are not learning much at all in your classroom?) we really just need to see that change doesn't have to be all that difficult or time-consuming. All we might require is some basic help in how to make our classrooms student-centred and how to reduce the content. How easy is that?

Student Centred/Outcomes Focused: How do I do That?

Once you have trimmed back the content, you are halfway there. You have set the scene for increasing student understanding. You can now focus on things in depth rather than dealing with them superficially, which is often what happens when speed of coverage is an important consideration, as has been the case in the past.

The next step is to allow students to work at their own levels and rates of cognitive development and understanding. The best way of doing this is to give them problems to solve which allow individual entry points and allow them to extend their capabilities as much as they like. Open-ended investigations facilitate this process. An open-ended investigation begins with a problem to solve. A relevant problem is best if it interests and motivates students. Examples for students in the middle years of schooling might be:

1. Peter sits close to the window in his maths class. He notices that the shadow cast by a small tree constantly changes, depending on the time of day.
   How does the length of a shadow and its direction change during the day?

2. Walking through the National Park on the long weekend, Judy notices that different rocks she picks up have different sized crystals in them.
   What factors affect the size of crystals?

3. Kerry has just had her hair acid-permed, and her hairdresser says she should use a very alkaline shampoo when she washes it. She decides to test some herself.
   What type/brand of shampoo has the highest pH?

All of these examples allow students to plan their investigation according to their individual level of ability and readiness. Ideally, they could choose their own equipment to use, but this is sometimes not feasible or possible. Teachers can begin by providing a list of suggested equipment from which students can choose.

How far a student proceeds with the investigation is entirely up to him/her. In the case of the first example above, students can achieve understandings ranging from how the Earth's behaviour affects the different seasons to how the sun affects the behaviour and features of other planets, and is itself influenced by other stars and components of the universe, or move to even higher levels of understanding such as the nature and behaviour of different stars, constellations, and so on.

In the case of the third example above, student understandings can range from determining that acids and bases have particular physical and chemical properties, through understanding that a pH value describes the extent of a relationship between H^+ and OH^- ions, to being able to write simple chemical equations that show how acids and bases produce ions in solution.

Teach Investigative Process Skills During The Investigations

It will obviously be essential for teachers to teach students how to plan - only one variable tested at a time, how to conduct an investigation where repeat trials are necessary, how to present data in tables and graphs, and other investigation skills - so they have some idea of the scientific processes involved. These are skills students can learn as they work through investigations. In this way, teachers are supporting and guiding students in their movement to higher levels of conceptual understandings.

Many students can be very lazy in their thinking and reluctant to begin a task, particularly where they are used to closed investigations that are totally prescriptive and where little self-planning is required. Initially, the majority of students will ask "what do we do?" and moan that they "don't know how to do it." Scaffolding, or frameworks, will be necessary for the majority of students at first, so that they can build their confidence with planning, evaluating, and other aspects of investigating with which they often have had little past experience. This scaffolding can gradually be removed as the students gain in confidence and skill. They will need encouragement and support to take risks and to test out their ideas so that they can extend their thinking each time.

Some students will find this much easier than others, depending on their confidence and thinking skills. Many teachers will find this change more difficult than their students, being required to facilitate and guide students in their efforts rather than give the answers at the outset. Teachers will need to encourage students to elaborate and talk about their initial findings and responses. This evaluation process will lead to students discovering their own mistakes, refining their ideas, and hence developing their understandings further.

Resources for Open Investigations

Sewell and Smith (2002a, 2002b, 2002c, 2002d) have written four books for teachers to guide them in the changes outlined above. Each is a book of investigations that focuses on one of the four main areas of science concepts: Earth and Beyond, Energy and Change, Life and Living, and Natural and Processed Materials. By helping teachers to focus on key conceptual areas, they may play an important part in enabling teachers to cut content effectively. Each book contains 40 open investigations, each with a student page that guides students through the investigation. Appendix A contains an example.

A feature of these resources is a discussion of current research on common student misconceptions associated with every problem, and suggestions for helping students overcome these. Each investigation is also accompanied by a large number of related activities and suggestions for extended research, making it possible for a whole unit of work to be built around the open-ended problem. Finally, a series of judgements enabling teachers to differentiate each student's level of understanding based on their investigation work accompanies each investigation.

These books are designed to not only help students progress in their understandings of the investigative processes and concepts of science, but also to help teachers in their understandings as they develop the skills to be outcomes focused rather than content focused, as may have been the case in the past. It is important to also realise that open investigations are just one way of helping your classroom to become more student centred. Other strategies exist to facilitate this change. Using this strategy and the above resources (or other open-ended investigations) will merely serve to facilitate the change process. Coming to grips with open investigation strategies is merely an effective starting point for teachers who don't know where or how to start.

In Conclusion

Both teachers and students will need to persevere, and resist the temptation to revert to the traditional, closed style of investigation, where planning and method are prescribed in the minutest detail. The important thing is that to take on this new role, teachers will have to forgo their desire to appear all-knowing, and direct students in their efforts to find out for themselves. Developing a Socratic approach – answering a question with a question - to lead students towards their own solutions is vital in today's classroom. In the modern world, it is not always important to know the facts. Rather, it is important to be able to find out the facts. This does not mean that science teachers do not need a strong conceptual understanding. To facilitate students' construction of knowledge, it is desirable that teachers possess an in-depth knowledge of subject material if misconceptions are to be both avoided and overcome. The important thing to keep in mind is that "Rome wasn't built in a day," that change takes time. Where reform is to occur, small steps forward are better than none at all.

Science curriculum reform addresses the premise that science teaching is based not only on what is taught, but also on how it is taught. Students need to be given time to develop a thorough understanding of essential concepts that will provide building blocks for future learning. Reducing the content addresses the time issue, while open investigations allow students to develop their understandings according to their individual readiness. The above suggestions for getting started with curriculum reform are simply that - suggestions. Both of them represent serious challenges to the science teacher. Change is rarely easy, but these thoughts may serve to facilitate change for those teachers who do not know where, or how, to begin.

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