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Ideas for enhancing primary and high school science education

Did you Know?

Oil and Water do Mix

Contrary to what is standard knowledge, oil and water do mix. Removing the gas from an oil/water mixture (1 L of water, for example, contains about 20 mL of dissolved gas) allows oil droplets to disperse in the water. Practical applications might include the cleaning of clothes without the need for detergent, the quick and safe delivery of insoluble drugs inside the body, and a revolution in many processes in the food production, perfumery, and drug manufacturing industries. For further information, please visit http://www.abc.net.au/catalyst/stories/s1314925.htm#transcript .

Rethinking Unsupervised Summative Assessment

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Abstract

Unsupervised summative assessment has become a feature of the educational landscape in various educational jurisdictions around the world, including the state of Queensland in Australia. However, I suggest it is an invalid and unnecessary practice that can impact negatively on the affect of students, call for a reconsideration of its use, and point to an improved way forward.

It is now over 30 years since Queensland students last sat, in each subject at the end of both Years 10 and 12, public examinations designed and marked by personnel external to schools. During the ensuing decades, and in conjunction with the implementation of school-based assessment, the types of assessment tasks being used in science education has broadened, and this is to be welcomed. However, it has also become accepted practice for senior (Years 11 and 12) syllabi to provide for unsupervised assessment tasks to be included in summative assessment. In view of especially the high-stakes nature of such summative assessment during the senior years of secondary education (e.g., where Years 11 and 12 assessment is used as the sole selection criterion for some courses of further study), I argue that such a practice is unnecessary, invalid, unfair, and promotes cheating.

Unsupervised assessment makes it easier for students to use dishonest practices to gain better results. For example, they might copy from other sources, collude with peers, get help from a relative, or pay a tutor to complete work for them, and here in Australia, whistle blowers working in tutorial academies and the popular media have been bringing the latter practice to light. Why should students, because of their favourable geographical location or network of contacts, or their financial means, be allowed to gain an advantage over peers by engaging others to do work for them? Such a practice lacks educational equity, deprives students of the feeling of satisfaction that comes from work well done, and probably even impacts negatively on their self-esteem.

Students themselves believe cheating to be a problem (Godfrey & Waugh, n.d.). In a reply to recently sharing my concerns about this issue with an international audience, I received the following from a Bangladeshi student: “I would like to thank you, because I have come to know that this is a problem in other parts of the world, as well as ours. Recently, I was disappointed, as one of my classmates had his assignment done by another meritorious student, while I worked hard to do mine myself” (personal communication, September, 2005).

Appealing to students’ moral code, or code of honour, is insufficient, and students are quick to tell us so (Godfrey & Waugh, n.d.). Common sense suggests the same, yet we find suggestions that procedures such as having students acknowledge all sources of help and keep a record of their progress with a task will somehow suffice. What student is going to tell a teacher that his or her parents paid for a piece of work to be done, or that his or her mother conducted the library research? For me, other practices such as periodic checking on progress by the teacher, student oral presentations (e.g., “Show and Explain”), conversations with a teacher, and a rubric completed by parents or guardians similarly fail to guarantee valid evidence as to student ownership of work. If students cheat, it is because they are allowed to, and this is what is presently happening.

It seems, then, that some fine-tuning of such practices might be desirable, and I think a careful analysis of the alternate policy of summative assessment coming from supervised tasks only is warranted. This is not to say that cooperative and unsupervised tasks do not have a role in education. Indeed, quite the opposite. Both are very highly recommended, as they facilitate even better learning outcomes and the development of important life skills. However, I’m suggesting that they be used for formative (practice) assessment only. I have long resisted the notion that the quality of a group product is also an accurate reflection of the achievement of each student in the group. If, for example, it is deemed appropriate to assess students’ ability to work with others, or to network, then we need to consider how this may be done validly. Interestingly, though, while syllabi promote cooperative learning as a learning strategy, it can at the same time be conspicuous by its absence in the general objectives of the syllabi--from which one might well assume that it is not to be assessed summatively.

The revised policy also wouldn’t mean that summative assessment need be restricted to paper-and-pencil examinations alone. There is scope for performance and other types of authentic assessment, as long as it is supervised. The emphasis should be on deciding exactly what it is we wish to assess summatively and then devising a supervised assessment technique to accomplish it. Allow me to describe a few examples of where such thinking might lead.

It must be some 20 years ago now since I first invited Year 12 Physics students to design and carry out individual, extended experimental investigations. The richness of learning, and the quality of outcomes, from this activity was enhanced by providing the option for students to work, over quite a few months, with a mentor from the community, who was typically a person involved in a science-based, or science-related, field. However, while the investigations could be designed and carried out in collaboration, and were also eligible for various state and national competitions, most of the assessment associated with this task was formative. I could not justify, for example, marking students summatively for their experimental design, because there was no guarantee that it was their work. Rather, experimental design was taught in class via a consideration of the different types of design weakness--and there are a relatively limited number of them-- and students were assessed using items on a supervised exam that sampled these weaknesses.

Experimental report writing, essays, research reports, and the like, for summative assessment, can also be done in class and supervised. However, the conditions for the task may vary, depending on what is to be achieved by the assessment. If recall of content is also deemed important, students would not be allowed to have notes. If one is assessing their ability to write, though, brief notes may be appropriate. Peter Roberts (personal communication, 2005), of Tullawong State High School, Queensland, Australia, for example, allows limited notes in the form of 15 key words or phrases, with a maximum of six words per phrase. It should not be a concern if students have sought "outside" help on how to write, because the bottom line is that they have learned, and the assessment task is validly reflecting what they have learned. While other processes, such as the ability to summarise information, draw conclusions from data, and present citations and references (or a bibliography) using the required style could also be assessed using supervised, pen-and-paper test items, still other processes, like the ability to locate library resources, would require a different approach.

Until relatively recently, I wouldn't have thought that a teacher would consider sending a set of traditional physics problems, say, home with a student and subsequently marking the responses summatively. So, appreciate how astounded I was to hear a teacher saying that, having marked such responses, she decided she couldn't use them "because the marks were too good"! Not only is this assessment not valid, but it is surely alarming that this teacher apparently didn't even consider that possibility before assigning the task. The "pendulum" appears to have swung too far. Then, there was the other teacher who told me that it doesn't matter how his students produced the work; as long as they did, they were entitled to receive credit for what they had produced. This philosophy is not for me. As an analogy, I have no difficulty with rewarding someone for cooking using a cookbook, but I do have much difficulty with the notion of a chef cooking with, or for, someone who is then credited with the quality of the outcome. When I'm being operated on, I want the confidence that comes from knowing that the certificate the surgeon has been awarded is based on tests that he or she sat himself or herself!

I regularly hear the argument that "if it doesn't 'count,' students won't do it," with it being considered necessary to use the leverage of summative assessment to pressure students to complete tasks. However, I also think this is misguided. Students need to recognize the benefits, to summative assessment results, that can come from practicing tasks and receiving formative feedback--and many students do. However, for any one or more of a variety of reasons, others will choose to forfeit such opportunities. A student may conclude, for example (and rightly or wrongly), that he or she is already sufficiently accomplished in the skills required by a particular assignment and decide to not do it. While teachers can provide learning opportunities, they surely cannot be responsible for all the decisions students might make about how they respond to such opportunities. In particular, and for the reasons being shared in this paper, it certainly seems unsound to implement a policy that uses the invalid summative assessment of unsupervised tasks, and which impacts negatively on all students, in an effort to get greater effort from some.

This concern about the use--or, rather, misuse--of unsupervised, summative assessment may not be such an issue at lower stages of education, where such high stakes are not involved. However, in the interests of consistency, it may be desirable to adopt a similar supervised-summative-assessment-only policy at all stages of education within a jurisdiction. As an added bonus, increased emphasis on supervised summative assessment might also have the welcome associated effect of reducing the excessive mandated academic workloads that students can experience in connection with the adoption of school-based assessment frameworks.

Reference

Godfrey, J., & Waugh, R. (n.d.). *Students' perceptions of cheating in Australian independent schools*. Retrieved October 21, 2005, from http://edoz.com.au/educationaustralia/archive/features/cheat.html .

Demonstration

While the activities in this section of *SER* have been designated demonstrations, some might easily be structured as hands-on student learning experiences. Although some sample lesson sequences may be included, the notes provided both here and in the following section are meant to act primarily as stimuli for classroom activities and to provide teachers with background information, so please modify any sample pedagogy as you see fit.

Identify the Number

Needed. Sheet of paper and a biro or pencil.

This activity provides practice in the skill of asking questions, a process that is central to enquiry. Choose a number from 1 to 1,000, secretly write it on a piece of paper, and fold the paper to conceal the number. Invite students to ask yes/no questions (i.e., questions to which you can reply either *yes* or *no*) aimed at identifying the number. Each student in the class is permitted to ask one question only until all students have had a turn.

On the board, record each student's name, the question asked, and the response it received. (With a new class, having students say their names helps all to put names to faces.) When the class is close to identifying the number, invite the students to confer, helping those who are yet to ask a question to come up with more narrowing questions.

When a question identifies the chosen number, display it from the folded sheet and ask the student why he or she did not ask that question earlier. Students will recognize the need to learn from the answers to other questions first--just like scientists do. Record the number of questions needed to identify the number, and then repeat the activity.

Variations might include choosing a number between 1 and 10,000 (a greater challenge), having a student lead the group, having students themselves record the students' names, questions, and responses, and requiring students to identify an object hidden in a box.

Source: Sitzman, D. (2005). Pick-a-number. *Science Scope*, *29*(1), 58-59.

Student Activity

Reminder: Appropriate risk assessment, supervision, and guidance are necessary.

Collisions

Needed. A ruler with a groove down the centre, six small marbles, one large marble, two wooden dowels (or similar, such as two pencils), one large high-bouncing ball, and one table tennis ball.

Invitation. Collisions between objects follow certain rules, and the study of collisions can provide much useful information. For example, scientists can use the evidence after an accident involving two cars to work out how fast the cars had been moving before they collided. By studying the collisions between the very small particles that make up atoms, we can learn how to control nuclear reactions. In this activity, you will study some interesting collisions.

Exploration 1. Please follow the following steps:

1. Place five small marbles in the groove near the middle of the ruler, so they form a straight line of touching marbles. Place the other small marble in the groove near one end of the ruler.
2. You are going to use a wooden dowel, like a pool (or billiard) cue, to strike the small marble and propel it towards the group of five marbles so it hits them firmly (but not so firmly that any marbles leave the groove). Predict what will happen.
3. Have your partner stand near the other end of the ruler to catch any marbles that go that way, and try it. What did you observe? Does one marble only move away from the other end? It should.
4. Predict what will happen if you strike two touching marbles with the dowel and propel them towards four marbles. Try it. What happened? (Two marbles should move away from the other end.)
5. Repeat for three marbles striking three marbles, four striking two and, finally, five moving marbles striking one marble only.
6. Do you see a pattern in these results? What is the pattern?

Concept introduction. Yes, there is a pattern. When a certain number of marbles strikes others in a line, this same number of marbles moves off from the other end. (You can also try this experiment at home by using coins that are made to slide across a tabletop. A Newton's Cradle, comprising a series of steel ball pendulums and available from some gift and novelty stores, as well as scientific suppliers, demonstrates this same phenomenon.)

You might think that, when marbles collide, many other results are possible. For example, when one marble strikes two others, perhaps it might slow down and both the other marbles might move off with the same speed at the other end. However, this does not happen. Collisions follow certain rules, and it is these rules that scientists study and use.

Exploration 2. Let's now study the collision between a small marble and large one.

1. Place a small marble in the groove at one end of the ruler and the large marble in the groove at the other end. With one student at each end, each student will use a piece of dowel to strike his or her marble, at the same time, so they move towards each other and collide near the middle of the ruler. Predict what will happen.

2. Try it. What happened?

Concept introduction. When a large marble strikes a small one moving in the opposite direction, the speed of the large marble does not change much, but the small marble bounces away very quickly. (In fact, light bouncy objects move away from heavy bouncy objects with a speed about twice the speed at which the heavy bouncy object is moving, regardless of the speed the light object has before the collision.)

Multiple ball bounce. You can do this same thing in a different way. First, test how bouncy the high-bouncing ball and table tennis ball are by dropping them on the tabletop and seeing how high each bounces. Next, sit the table tennis ball on top of the high-bouncing ball, hold them about 10 cm above the tabletop, and drop them so they fall together. What happens after they strike the table?

After the heavy, high-bouncing ball strikes the tabletop, it begins to move upwards. However, the light, table tennis ball is still moving downwards, and after they collide, the lighter ball again moves away quickly, just like before with the light and heavy marbles. The same thing happens when a rolling bowling ball (heavy) collides with a beach ball (light) of about the same size moving in the opposite direction.

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Learning from History: A Lesson on the Model of the Earth

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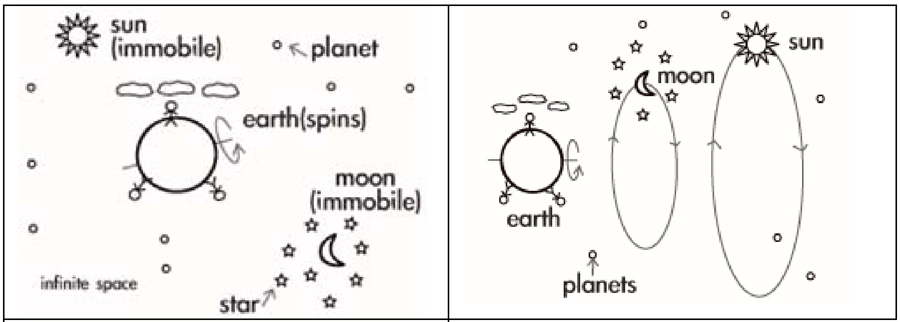
Abstract

It is suggested that historical material concerning the model of the earth be utilised in the science classroom to construct narrative explanations. The article includes the various ancient models of the earth, the discovery of the spherical earth model, and the arguments and experiments coupled with it. Its instructional gain may lie in the consequently created situations in which students are led to reflect on their own concepts/models of the subject and to appreciate the diversity in thinking about it.

Introduction

Research during the last decades has shown that young students construct for themselves alternative models of the earth as opposed to accepted scientific knowledge (Liu, 2005a, 2005b; Nussbaum, 1979, 1985; Nussbaum & Novak, 1976; Sneider & Poulos, 1983; Vosniadou & Brewer, 1992, 1994). Most telling is the evidence that "synthetic models" (Vosniadou & Brewer, 1992, 1994), such as a hollow-spherical shape for the earth with people living inside on a flat ground, arise while children try to reconcile the scientific model of the spherical earth with their daily observation of a flat ground. Liu's (2005b) recent study of 8- to 12-year-old Taiwanese and German students' conceptions of the universe reveals that, looking at solely the shape of the earth, the majority of the students give scientifically correct responses. However, when the questions are extended to the spatial relations of the earth and the obvious celestial objects, it becomes clear that the children actually have difficulty relating what is viewed on the surface of the earth with what is explained by other people, such as the horizon as an indicator of the spherical shape of the earth and the rise and setting of the sun as the result of the earth orbiting the much bigger sun. This kind of difficulty gives rise to statements like "no cloud is present beneath the earth" and "earth stays still, and the sun and the moon circle around it," as shown in Figure 1.



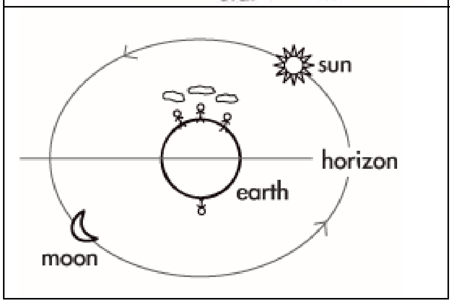


Figure 1. Examples of students' models of the universe with an imaginary horizon and the sun "rising and setting."

At this point, it seems to be clear that students' difficulty in understanding the earth model is derived from the perspective students take from where they are located. To understand the sphericity of the earth and its position in the universe, the student must first realize there is a difference between what is seen on the surface of the earth, while the observer is a tiny point, as opposed to the whole earth, and outside the earth, while the earth can be fully captured in the view. That is, the difference between the perspectives taken on and beyond the earth should be recognised and comprehended. Yet simply describing this difference may not be sufficient to ensure meaningful learning of the subject. We need to lead students to a situation in which they can reflect on their own ideas in a way that the underpinning of these ideas is emphasized and thereby proceed to understand and appreciate diverse thoughts derived from their connected contexts.

It should be an instructionally meaningful, although not the only, approach to creating such a situation through the use of historical material. It is suggested that narrative explanations of the structure of the earth be constructed, including the various ancient models of the earth, the discovery of the spherical earth model, and the arguments and experiments coupled with it. The instructional gain may lie in the consequently created situations in which students are led to look at their own concepts/models of the subject, as well as others. Furthermore, there is a potential to convey some aspects of the nature of science, such as the interrelations between concepts/theories (models) and methods.

Historical Models of the Earth

Everyday experience, in the past as in the present, is compatible with the idea of living on a flat earth. Ancient people genuinely believed that if you went far enough you would fall off the edge. From around 3,000 B.C. onward, man has articulated and documented various ideas about the shape of the earth in different temporal and spatial settings. For example, the ancient Chinese described the earth as a chess-board, whereas their Egyptian counterpart thought the earth was a rectangular box. The early earth models very often show a close linkage to man's pursuit of an "ideal" structure of the world.

Looking at the Western world, the story of man's ideas about the earth's shape and its position can begin with the Babylonians (before 3,000 B.C.), virtually the earliest wisdom we can reach, who imagined the earth being like an oyster and occupying the central place of the universe. In this model, the northern half of the earth was called the upper, associated with life and light, whereas the southern half was called the under, associated with darkness and death. Each of the halves are composed of seven stages, and beyond the uppermost stage we find the stars.

During the 8th century B.C., Homer described, in his remarkable mythological text, that the earth is flat like a shield, upon which is the land, a single island, surrounded by the ocean. The sky, or heaven, is seemingly pictured as solid, as he used metaphors such as iron or bronze in several passages.

It is Anaximander (about 555 B.C.) who established the first recorded mechanical model of the universe, in which the earth is a cylinder with the sun, moon, and stars located on concentric rotating cylinders. Planets were not explained. The sky surrounded the earth, and beyond the sky was a region of fire. There the sun, moon, and stars were holes in the sky, through which the fire could be seen. This view should be taken as revolutionary, as previously all heavenly events and entities had always been interpreted in terms of gods.

Early natural philosophers soon arrived at the idea of the spherical earth. It is around the 6th century B.C. when a spherical earth became self-evident in the western world. The spherical earth was often thought to be floating on water. However, Greek philosophers also concluded that the earth could only be of a spherical shape because that, in their opinion, was the "most perfect" shape.

Thales (640-562 B.C.) made one of the first attempts to explain the nature of the universe in philosophical terms. He proposed that the earth is shaped like a ball, floating on a water base at the bottom of a big bubble in which the world exists. Outside the big bubble is the universe, a gigantic ball of water, in which the heavenly bodies float. Most significant about his thoughts is the belief in the spherical shape of the earth, and the use of navigators' narratives, which reported the variation of the positions of stars and constellations going from one region to another of the world, to support his assertion.

Pythagoras of Samos (580-500 B.C.) also recognized the sphericity of the earth, most probably as a result of his belief that the sphere was the perfect shape rather than any scientific reasoning. Nevertheless, he went about searching for observational evidence to support this assumption. What convinced him was the lunar eclipses and the way ships disappear from view on the horizon. During a lunar eclipse, the earth casts a round shadow on the moon that can only be caused by the earth being a sphere. The phenomenon that when a ship returned to port, first its mast tops, then the sails, and finally its hull gradually came into view can only be explained when the earth is spherical (Figure 2).

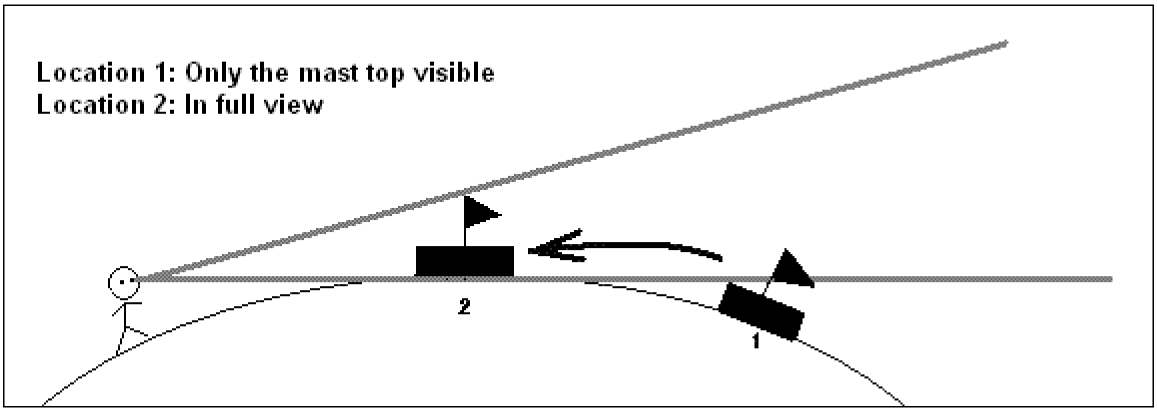


Figure 2. The way a ship appears on the horizon.

Aristotle's and Erathostenes' Discovery of the Sphericity of the Earth

It is Aristotle (384-322 B.C.) who set out to "study" this idea of the sphericity of the earth and to give reasons for it. His reasoning illustrates the attempts and the paths to view the earth from the perspective taken beyond the surface of the earth, and consists of three pieces of observed evidence. The first, and strongest, reason was lunar eclipses, as already contended by Pythagoras. During a lunar eclipse, the earth's shadow on the moon is always round. The only object whose shadow is always circular, no matter what its orientation, is a sphere. Aristotle wrote, in his *On the Heavens II*:

> Further proof is obtained from the evidence of the senses. If the earth were not spherical, eclipses of the Moon would not exhibit segments of the shape which they do. As it is, in its monthly phases the Moon takes on all varieties of shapes - straight-edged, gibbous and concave - but in eclipses the boundary is always convex. Thus, if the eclipses are due to the interposition of the Earth, the shape must be caused by its circumference, and the Earth must be spherical. (Evans, 1998, p. 47)

Aristotle's second reason for the spherical shape of the earth was taken from another predecessor, Parmenides, and based on the different heights of the stars observed in various parts of the world. The following excerpt clearly illustrates his argument:

> Observation of the stars also shows not only that the Earth is spherical but that it is of no great size, since a small change of position on our part southward or northward visibly alters the circle of the horizon, so that the stars overhead change their position considerably, and we do not see the same stars as we move to the North or South. Certain stars are seen in Egypt and the neighbourhood of Cyprus, which are invisible in more northerly lands, and stars which are continuously visible in the northern countries are observed to set in the others. This proves both that the Earth is spherical and that its periphery is not large, for otherwise such a small change of position could not have had such an immediate effort. (Evans, 1998, pp. 47-48)

Lastly, Aristotle also produced the argument that all earthly substances move towards the center, and thus would eventually have to form a sphere:

> Its [the earth] shape must necessarily be spherical. For every portion of earth has weight until it reaches the centre, and the jostling of parts greater and smaller would bring about not a waved surface, but rather compression and convergence of part and part until the centre is reached. The process should be conceived by supposing the earth to come into being in the way that some of the natural philosophers describe. Only they attribute the downward movement to constraint, and it is better to keep to the truth and say that the reason of this motion is that a thing which possesses weight is naturally endowed with a centripetal movement. When the mixture, then, was merely potential, the things that were separated off moved similarly from every side towards the centre. Whether the parts which came together at the centre were distributed at the extremities evenly, or in some other way, makes no difference. If, on the one hand, there were a similar movement from each quarter of the extremity to the single centre, it is obvious that the resulting mass would be similar on every side. For if an equal amount is added on every side the extremity of the mass will be everywhere equidistant from its centre, i.e. the figure will be spherical. (Stocks, n.d., section 14, ¶ 4)

Presumably, the most impressive demonstration of the earth's spherical shape was presented a little later by Erathostenes of Alexandria (276-194 B.C.). The shadow of a pillar was measured, at noon on the same day (the summer solstice), in each of two places of different latitudes, Alexandria and Syene (the modern city of Aswan, located south of Alexandria, on the banks of the Nile). His assumptions include:

- The earth is spherical (which seemed to be already commonly accepted in his time).
- The sun is very far away, compared to the size of the earth. Therefore, rays of sunlight striking different places on the earth can be considered to be parallel.
- Alexandria is due north of Syene (which is not exactly true, but it introduces a minor error only into the result).

Erathostenes recorded the one in Alexandria to be a certain length and precisely at an angle of 7.2°, whereas the other in Syene, on the tropic of Cancer, was not measurable because the sunlight went straight down from above the pillar. The results can be explained only on the basis that the earth is spherical. Furthermore, knowing the distance between the two places of almost the same longitude to be 5000 stades (a common unit of length in the ancient world, where an Egyptian stade is approximately 0.157 km), Erathostenes calculated the length of the earth's polar circumference (by dividing 360° by that shadow angle and multiplying by the above distance [see Figure 3]) to obtain 39,250 km, a value similar to that used today.

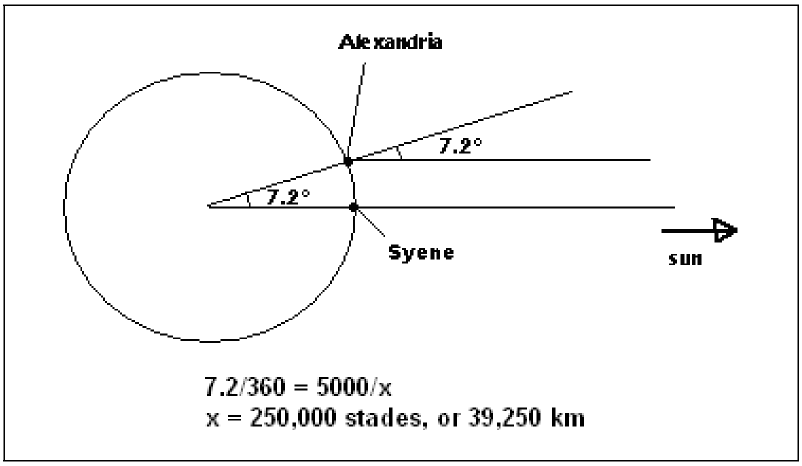


Figure 3. Erathostenes' calculation.

As late as the 16th century, the same arguments were used for the sphericity of the earth, as Nicholas Copernicus (1,473-1,543 A.D.) wrote in his work *De Revolutionibus*:

> The earth is also spherical, since it presses upon its center from every direction…. For a traveller going from any place toward the north. That pole of the daily rotation gradually climbs higher, while the opposite pole drops down an equal amount. More stars in the north are seen not to set, while in the south certain stars are no longer seen to rise … evening eclipses of the sun and moon are not seen by easterners, nor morning eclipses by westerners, while those occurring in between are seen later by easterners but earlier by westerners.
>
> The waters press down into the same figure also, as sailors are aware, since land which is not seen from a ship is visible from the top of its mast. On the other hand, if a light is attached to the top of the mast, as the ship draws away from the land, those who remain ashore see the light drop down gradually until it finally disappears, as though setting. (Rosen, n.d., chap. 2, ¶ 1, 2)
>
> The earth together with its surrounding waters must in fact have such a shape as its shadow reveals, for it eclipses the moon with the arc of a perfect circle. Therefore the earth is not flat, as Empedocles and Anaximenes thought; nor drum-shaped, as Leucippus; nor bowl-shaped, as Heraclitus; nor hollow in another way, as Democritus; nor again cyclindrical, as Anaximander; nor does its lower side extend infinitely downward, the thickness diminishing toward the bottom, as Xenophanes taught; but it is perfectly round, as the philosophers hold. (Rosen, n.d., chap. 3, ¶ 5)

Therefore, the spherical shape of the earth was determined, repetitively and consistently, based on (1) the positions of the stars observed in different places, (2) the way in which a ship disappears from sight after departing from land, and (3) the occasional lunar eclipses.

Classroom Practice

This historical material can be used to assist students in understanding different early models of the earth, the backgrounds that created these ancient models, and the evidence provided to support them, and in turn help create a setting in which students may start to discover their own models and discuss them. A list of suggested activities and procedures for a science lesson plan follows:

1. Encourage students to brainstorm a model of the earth based on their everyday observations.
2. Have students discuss their models and further discuss what the term *model* means.
3. Present several historical models of the earth, along with their settings and explanations provided by scientists.
4. Have students reflect on the relations between a model, explanations it provides to account for the phenomena, and the background of its time.
5. Have students replicate historical observation and experiment, such as observing the ship appearing/disappearing on the horizon and conducting Erathostenes' measurement in a similar way.

Before introducing the historical material, the teacher may first ask students to describe the motion of the sun, moon, and stars in the sky and further encourage them to construct a model of the earth based on only this kind of observational information from the naked eye, as the people in the ancient world did. They should also have the opportunity to present their models to the class, and to ask questions and discuss how well each model explains what we see in the sky. In addition, it can be interesting to discuss the term model, perhaps described as a person's explanation for something that has been observed, including the explanations that students provide.

While introducing an historical model, students should be encouraged to imagine that if they went to school at its time, they might have been taught that this model was the only way to explain the observations of the sun, moon, and stars. For each model, and the explanations that go along with it, students should also be encouraged to think about how these explanations might have evolved and how they reflect the common beliefs and surroundings of the people who created them.

Students can re-do the observations and experiments that are often technically simple but nevertheless brought about plausible alternative arguments. The early astronomical models were basically established through sky-gazing. Astronomers in different places of the world observed and documented the sky carefully and thereby developed their visions of the universe. As mentioned in the previous section, the model of the spherical earth was historically supported by three pieces of observational evidence with naked eyes: the changing positions of the stars due to the observer's locations, how ships disappear on the horizon, and lunar eclipses. It should be reasonable that students may revise their concepts and models if similarly watching the sky and the horizon carefully. Through the observation of the sun, moon and stars, from different angles (e.g., from the sea [horizon]), students may further develop a sense of spatial relations of heavenly bodies and the earth.

Students' direct encounters with natural elements will most likely arouse questions and doubts. Students should be encouraged to express their ideas and to offer solutions, and furthermore learn to understand and accept different points of view. At this point, they are on their way towards understanding the multiple hypotheses and clarifications that form part of the process of scientific enquiry. We can then expect our students to appreciate possible models, different from the concrete ones essentially linked to emotion, that are linked to imagination and reasons. The earth, for example, is apparently flat or irregular in shape, as we observe it on its surface, but is really spherical as we now understand it. As another example, young students often explain the day/night cycle as a result of the sun revolving around the earth, which is apparent in their everyday life, but what is real is that the earth's rotation gives rise to the alternation between day and night. The task for the teacher is to underline this contrasting feature while teaching the earth model in the classroom.

The experiment done by Erathostenes to measure the lengths of the shadows, at the same time in different places, can also be presented to, or even replicated by, secondary students in order to improve their understanding of the earth model. It illustrates an early, yet then advanced, approach to tackling the problem of the earth's shape and size. There is also the opportunity, in this kind of activity, for students to grasp some aspects of the nature of science, particularly the connections between concepts/theories and methods.

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Critical Incident

An Invitation

Readers are invited to send, to the Editor at editor@ScienceEducationReview.com , a summary of a critical incident in which you have been involved. A critical incident is an event, or situation, that marks a significant turning point, or change, for a teacher. The majority of critical incidents are not dramatic or obvious, but are rendered critical through the analysis of the teacher (see Volume 3, p. 13 for further detail). You might describe the educational context and the incident (please use pseudonyms), analyse the incident (e.g., provide reasons to explain your observations), and reflect on the impact the incident made on your views about the learning and teaching process. Upon request, authors may remain anonymous.

We have undoubtedly all done things about which we were very pleased, and perhaps done other things about which we did not feel so pleased, and we all need to remain reflexive of our practice. While teachers will view an incident through the lenses of their own professional experiences, and may therefore explain it differently, this does not detract from the potential benefits to be gained from our willingness to share our experiences and thus better inform the practice of other teachers.

Investigating With Models

By: Bill MacIntyre, Massey University College of Education, Palmerston North, New Zealand
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Background. Students, in their second year of a teacher-training programme, enrolled in a year-long Studies in Subject course to enhance their science content knowledge. A module in the course focused on astronomy understanding and one pedagogical strategy used in teaching this is the use of 3-D models. Students were encouraged and "pushed" to engage in classroom demonstrations and discussions using 3-D models.

Since the teaching used 3-D models, it seemed natural to assess individual student understanding using 3-D models. After 3 years of using this form of assessment, one student I was assessing at the time stopped in the middle of modeling an answer. I waited for a couple of minutes and then asked the student what was going on in her mind with regards to the question. She replied: “I am trying to remember how you used the 3-D models to answer this question.”

The impact of that statement pushed me to review how I use 3-D models in my teaching of astronomical concepts. I suddenly realized that students were not “teasing out” their astronomical understanding with the use of 3-D models, but mimicking what I had demonstrated to them in the classes. The reflection and analysis of my existing teaching approach caused me to change how I use 3-D models in the teaching of astronomical concepts. As a result of the reflection and analysis, the Investigating With Models approach (MacIntyre, Stableford, & Choudry, 2002) was developed, and is continuing to be developed with Intermediate (Years 7 & 8) and Secondary (Years 9-12) school students, as well as my tertiary students.

The development of the Investigating With Models approach was precipitated by the student mimicking, but a suggestion made by an external reviewer of the astronomy module, the plethora of educational research on alternative astronomy notions, and my own understanding of the conceptual change learning model forced me to look at, and try, another pedagogical approach. In the back of my mind, I was also struggling to find a way to get the teacher trainees investigating in astronomy, so that they further develop their understanding of the nature of science.

The Investigating With Models approach creates a learning situation that uses educational principles in an active learning environment. The ideas of effective teaching and learning are embedded in a systematic inquiry (investigation). The investigation allows students to confront their existing knowledge with new knowledge obtained through the investigative process. I knew that Baxter (1995) encourages pedagogical practices that involve a recursive process of challenging students’ personal notions of astronomical events by providing opportunities for them to test the plausibility of their own mental model. The process of investigating an investigable question (e.g., what causes day and night? What causes the seasons? What causes the different shapes of the moon?) engages students in the process of collecting evidence to support the 3-D modeling (concrete model) of their mental model--whether it is the original, or a modified, model. The conceptual change research indicates that students will not change to a more scientific explanation unless they are dissatisfied with their current explanation.

Asking the students to model their original explanation, and then attempt to model it again using the collected evidence, provides a basis for rejection/modification of the original notion if the evidence demonstrated in the 3-D modeling did not support the explanation. Having students observe the 3-D modeling of the explanations in small groups helps them to construct a new explanation, or modify an existing explanation, when they see that their original one is no longer valid. It is also a non-threatening way to elicit teacher trainees’ views and allow them to construct their learning around those views.

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Science Poetry

Reading and/or listening to poems that have been composed by other children their own age can inspire and reassure students as to their ability to understand and write poetry, and the science poems in this regular section of *SER* may be used for this purpose. Please find information about the *International Science Poetry Competition* at http://www.ScienceEducationReview.com/poetcomp.html .

My Huntsman Spider

There's a spider in my eyeballs,
She's exploding every day.
It's a problem, not a poem,
But I'll write it anyway.

Her legs are long like Christmas trees,
Her eyes are short, are hiding.
Her body's like a snowflake,
Her time she must be biding.

Until she springs on bedspring wings,
And tiptoes on her fingers.
She crawls across my eyelid things,
And in the dark she lingers.

I know she's just a shadow,
A shadow of the light.
That falls upon my retina,
When I close my eyes at night.

But my spider, still she lingers on,
Quietly exploding.
Like a program on the internet,
That's constantly downloading.

Elizabeth Waldron, 8 years
Australia

The Mystery of Stars

Look into the night
At the stars sparkling bright
How tiny, how white
From afar seems their light

But look closer and see
What colour they be?
Are they young, are they old?
Are they hot, are they cold?

Is the star really there?
Does light it still bear?
Or has it used all its gas
And is now seeking rest?

In the nebula stars birth
And discover their worth
Long life or large volume
Only one, they'll assume

It is there that they'll die
And it's there that they'll lie
Neutron star, even pulsar
White dwarf, growing cooler

So far from our Earth
So large in their girth
Stars hold so much mystery
Truths deeper than eyes can see

Kristen Tee, 15 years
Australia

What Uncouples Students' Goals from Students' Outcomes in Introductory Biology Courses?

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Abstract

On the first day of classes, most students in introductory biology courses (a) believe that their effort is the most accurate predictor of their academic success, and (b) are confident that they will work hard and earn high grades. Despite their optimism, many students do not follow through on their expectations, and their grades drop accordingly. When asked about their academic behaviors, many students provide misleading answers. A lack of academic motivation is what often uncouples most students' academic goals from their academic outcomes in introductory biology. These results are discussed relative to how biology teachers can help students succeed in introductory biology courses.

To read the full text of this article (7 pages), please **click here**.

Teaching Techniques

This regular section of *SER* describes thinking, cooperative learning, and other teaching techniques.

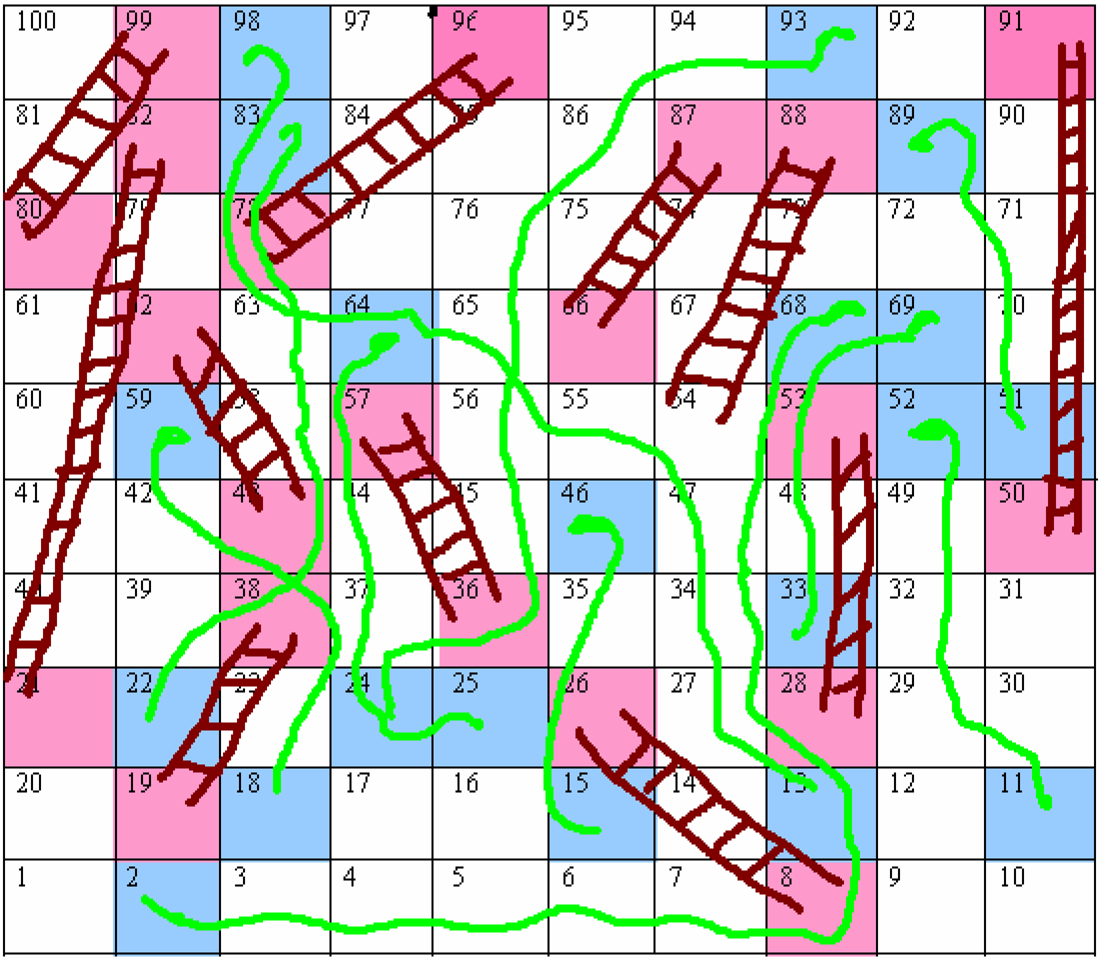
Snakes and Ladders

By: Sunitha Pillai, Kerala, India

The game of Snakes and Ladders can be used to teach, or to revise, a topic. This example is one I prepared for the topic Some Common Diseases, and it can be readily adapted for other topics without the need to construct an entirely different game board.

If using the game to teach the topic, the class might first be divided into groups and asked to name some common diseases, discuss their common causes, symptoms, and preventions, and summarize this information. Each group is then provided with a game board and accompanying text (see below), dice, and coloured markers.

The ladders indicate positive aspects of diseases and the snakes negative aspects. Each time a student has to climb a ladder, or go down a snake, he or she reads the contents of the relevant squares aloud to other members of the group. For example, a student landing on Square 8 "climbs" to Square 26 and says: "Covering your mouth while sneezing or coughing prevents the spread of microorganisms through air." Similarly, a student landing on Square 98 will move back to Square 13 and say: "Keeping garbage bins open helps to spread diseases." As an option, a teacher might construct a set of larger game boards, with the text written in the appropriate squares, for each topic.



Ladders

8 Covering your mouth while sneezing or coughing
19 Eating vitamin rich foods
21 Vaccinations

28 Immunization with BCG
36 Providing ORS
43 Anti-rabies vaccine
50 Eating food rich in Vitamin A
54 OPV drops
66 HCl in the stomach

78 Cilia in the inner lining of the nose
80 Antibodies

26 prevents the spread of microorganisms through air.
38 prevents deficiency diseases.
82 make the immune system produce antibodies.
53 provides immunity against TB.
57 prevents dehydration.
62 is effective against rabies.
91 prevents night blindness.
88 are effective in controlling polio.
87 destroys microorganisms that enter the stomach.
96 traps microorganisms and dust.
99 kill bacteria without killing the cells of the body.

Snakes

98 Keeping garbage bins open
93 Stagnation of water
89 Not isolating a TB patient

13 helps to spread diseases.
24 allows breeding of mosquitoes.
51 spreads the disease TB.

83 Eating foods deficient in vitamin C	22 causes scurvy.
69 Foods deficient in vitamin B1	33 cause beri beri.
68 Not vaccinating children with DPT	2 exposes children to diseases like diphtheria, pertusis & tetanus.
64 Eating iodine deficient food	25 causes goiter.
59 Foods deficient in vitamin D	18 cause rickets.
52 Drinking water that is not boiled	11 can cause cholera.
46 Not immunizing pets	15 can spread the rabies virus.

Engaging All Students in Cooperative Learning

By: Lynne Houtz, Creighton University, Omaha, Nebraska, USA lhoutz@creighton.edu

The choice to structure the learning experience cooperatively allows students to work together toward shared goals and to develop social skills through positive interdependence (Johnson, Johnson, Holubec, & Roy, 1984). Group work also allows more students to participate hands-on with limited materials.

Forming Groups

Groups can be formed in a variety of ways, depending on the teacher's perceptions of the individuals' behaviors and potential group chemistry. I have developed these categories for dividing students into groups.

Students self-select. Allow students to form their own groups. "Divide yourselves into groups of 4." Simple criteria may be added, such as "mixture of boys and girls, the same people you worked with yesterday, people you haven't worked with before." The pitfalls are obvious to any experienced educator, as students gravitate towards friends who typically have similar ability, behavior, and social group. Some students may feel left out.

Students can also self-select by interest in the topic or activity. "Those interested in dinosaurs may work at Station 1; those interested in the rain forest, Station 2, ..." In addition to the concerns listed above, group sizes can be lopsided.

Teacher selects by convenience. Possibilities include the following:

- Proximity (e.g., "work with the people at your table." "Work with the people in your row." "You 4 people in this area are a group").
- Count-off 1, 2, 3 ,4, 5 (e.g., "all the ones work at this table, twos this table, ..."). For novices, there can be some confusion with the counting and group size.
- Roster. Call names from the class list in alphabetical, or reverse alphabetical, order.
- Draw names (using tongue depressor sticks, tabs, or out of a hat).

Teacher selects by criteria. Thoughtfully select heterogeneous groups so students are mixed appropriately, taking into account gender, ability, behavior, social groups, cliques, and so on.

Novelty. If you have time and are in the mood, are prepared to trouble-shoot an imbalance in numbers, and can cope with students who may want to argue their eligibility for a group, consider some of these.

- Birthday month (e.g., all students born in January, raise your hand. You 2, plus 2 from February, are Group 1).
- Colors (e.g., “decide the defining color of your eyes, whether brown, black, blue, or green. Brown eyes, raise your hand. You 4 are Group 1, you 4 are a Group 2, ...”).
- If you are wearing blue raise your hand, ...
- Favorites (e.g., “we have been studying these five extinct species. If your favorite is the passenger pigeon, raise your hand. The Dodo bird . . . .”)
- Tune humming. Give each student a slip of paper with a familiar melody. Students locate others humming the same tune.
- Find your pack. Perhaps in conjunction with the study of animals that recognize members of their group by scent, distribute cotton balls soaked with distinctly recognizable fragrances in individual plastic sandwich bags. Perfumes, colognes, cooking extracts, and chemical products that are not harmful to inhale can be used. All who have the flower perfume are a group, vanilla extract are a group, vinegar are a group, and so on.

Organization

Try the following for allocating roles:

Role cards. Distribute cooperative role cards that have group identification on one side and job description on the other side.

Playing cards. Sort groups by the number on the cards (e.g., “all Aces sit at this station, deuces that station, ...” Or, assign a suit a specific role (e.g., Spade = Leader [keeps group on task, encourages everyone to participate]; Heart = Materials Manager [gathers materials for group when told, returns clean materials to instructor]; Club = Engineer [performs the hands-on procedural steps]; Diamond = Recorder/Reporter [lists the group’s observations, gives examples from the group during follow-up]).

Make all the roles sound equally prestigious. Clearly explain each role’s responsibilities. I’ve learned from experience that it works better if the person who makes the notes also reads and reports the notes or lab sheet results or minutes.

Once groups have been formed, clearly specify the instructional objectives for the group, the participation responsibilities of each role and each member of the group, and the interaction expectations. Clarify the social tasks as well as the science learning outcomes, and explain how each will be evaluated.

Monitoring

Monitoring group progress by proximity is essential. I often demonstrate different procedural steps as I move among different workstations and check on progress continually all around the room. I make sure that all students are contributing equitably and not hogging the leadership role, conducting all the material manipulation, or falling asleep on the job. Most members adjust behaviors to a simple reminder or question, such as: “Don’t forget to let everyone have a turn.” Therefore, unless obviously slacking, all members of the group earn the same score.

Evaluation

In addition to the lab sheet procedural steps, data, questions, and reports, incorporate items on group evaluation and individual participation with a checklist or rubric, as follows.

Task or outcome	Always	Sometimes	Never
We used our time wisely and stayed on task.			
Everyone worked cooperatively to solve problems in a peaceful manner.			
I contributed my ideas and information.			
I encouraged others to share their ideas.			

Records

Another challenge in cooperative group work is managing the paperwork, particularly if students are expected to retain work samples for portfolios for conferences or open house. In some cases, I find it helpful to keep all hands busy, expecting all members of the group to complete the lab sheet. At other times, it is more appropriate to copy one completed lab sheet and put it in each group member's folder.

Reference

Johnson, D. W., Johnson, R. T., Holubec, E. J., & Roy, P. (1984). *Circles of learning*. Washington, DC: Association for Supervision and Curriculum Development.

Ideas in Brief

Summaries of ideas from key articles in reviewed publications

Futures Studies and Science Education

By: David Lloyd, University of South Australia and John Wallace, University of Toronto
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The aim of our article, “Imaging the Future of Science Education: The Case for Making Futures Studies Explicit in Student Learning” (Lloyd & Wallace, 2004) was to argue for the inclusion of a futures perspective to science learning by reviewing the literature and making a case for the broadening, through futures work, of what has traditionally be considered science education. We discuss how futures education provides a dimension to science learning that allows students' own interests and concerns about possible futures to inform the science curriculum and by so doing values students' life worlds and worldviews. We show how this isn't just a novel idea, but a necessary one in these times of rapid change towards globalisation. We suggest that science is one way of knowing that students can call upon when addressing issues of personal, local, and global concerns and that the concepts and processes of futures studies is another that enriches these studies. We see science learning as needing to be associated, at least some of the time, with other ways of knowing in an integrated or transdisciplinary curriculum that addresses explicitly challenges that are social and often political. In our article, we focus in particular on futures studies as one way of introducing the practical and emancipatory interests needed to address social and political challenges. The work of futurists helps because they explore alternative futures in order to assist people in choosing and creating the most desirable future and are motivated by the ideal of maintaining or improving the welfare of humankind, which includes future generations, and the life sustaining capacities of the Earth itself.

There are four sections to the review. In the first section, we describe our own introduction to futures and comment on the status of futures studies in school curricula. Our futures in education work was initiated by a 1988 Australian bicentennial project which exposed us to the futures field of study and, in particular, to students' images of possible futures. We were motivated to do this futures work in science education because of our professional interests in science learning and what we saw as compelling reasons for the alliance of science and futures. In 1988, explicit use of futures in science education curricula was non-existent and even today is not strongly represented, although, as we discuss in the paper, there is now some acceptance.

In the second section, we look at a central aspect of futures studies; images and expectations of possible futures that individuals and communities hold. We define images of possible futures as mental tools that deal with possible future states and that are composed of a mixture of concepts, beliefs, and desires that affect student choices and guide decision-making and actions. So in this section we review what the literature and our own work says about the nature of students' images of possible futures, the importance of these students' views (using historical, psychological, and educational studies), and aspects of these images that have science-related content. This discussion forms a primary justification for futures in science learning. The evidence suggests that, at the very least, student images of possible futures provide useful starting points for science curriculum work, but might also be life-forming and central to student well-being. We conclude that whatever the interpretation placed on student images of possible futures, it seems that they are an integral part of students' worldviews and hence constitute prior knowledge that can influence motivation, conceptual development, and what is valued as knowledge.

Third, we provide a brief overview of the futures field of study with respect to its characteristics, history, and structure and examine a subset of futures studies, critical futures. We build on the idea that the futures field of study arises out of the anticipatory and planning characteristic of humans that are fundamental for human behaviour. Futurists claim that the most useful knowledge is knowledge of possible futures because it empowers individuals and communities to be proactive in planning for and actively seeking preferred futures. We look at the historical development of contemporary futures studies, its knowledge base, the epistemological foundations of futures work, and the methodologies and methods employed to study the future. We conclude this section by suggesting that the futures field of study is still developing and is interpreted differently by different groups of futurists, but that there is sufficient congruence and stability to make the futures field useful for educational purposes and to address the interests, concerns, and fears revealed in students' images of possible futures.

We argue that of particular use for educational futures is critical futures studies which merges the critical perspectives of Habermas with those of futures studies. It examines global contradictions and contrasts, and challenges the myths that technology and science are neutral, value free, and objective. We see this critical perspective as being as important in science education as concept development, problem solving, and technology development and argue that a critical futures approach to learning, and in particular science learning, provides a framework in which to value both the strengths of science and the humanities.

In the final section, we examine futures in education with a particular reference to science education. We discuss how futures studies, and themes that arise from student images of futures, intersect with science and outline how futures in education may contribute to effective and empowering science learning. We conclude that science learning, when combined with futures concepts and processes, can contribute to a teaching approach that promotes students' preferred futures images of hope and optimism and ways to deal with dystopian imagery which students call upon in the absence of any alternative philosophical and methodological frameworks. Futures studies can help to empower individuals in the present by providing positive images of possible futures and also encourage students' altruistic disposition by considering the needs of future generations.

In this final section, we also look at how science learning can contribute to the study of a number of themes identified in student images of possible futures. We describe a unit of work on fresh water ecology, and the need for quality fresh water by residents in South Australia, using a critical futures approach to learning. In this unit, a number of futures methods, including futures imaging, are used and students, having identified possibilities for preferred futures, develop ideas on how they can make a difference and devise strategies for getting there. The example illustrates how a futures dimension can develop imagination, creativity, thinking skills, and the development of a futures vocabulary and futures tools.

In Lloyd and Wallace (2004), we examined the literature on futures studies and, in doing so, argued the case for making futures explicit in school science learning. We contend that student images of possible futures, whether utopic or dystopic in nature, can be used as a way into exploring possibilities for future times and that science learning is a necessary part of this process.

Reference

Lloyd, D., & Wallace, J. (2004). Imaging the future of science education: The case for making futures studies explicit in student learning. *Studies in Science Education*, *40*, 139-178.

Research in Brief

Summaries of research findings from key articles in reviewed publications

Overcoming the Challenge of Teaching Open Inquiry

By: Michal Zion, Bar-Ilan University, Israel and Esther Shedletzky, The Hebrew University of Jerusalem, Israel zionmi@mail.biu.ac.il, esthersh@pob.huji.ac.il

Scientific inquiry is such an integral part of students' scientific learning that it was established by the American National Science Education Standards as one of the key standards in science education. Inquiry-based activities encompass a broad spectrum, ranging from structured and guided inquiry (instructor-directed) to open inquiry (student-directed). In the course of structured inquiry, the teacher initiates the inquiry question and procedure, but allows the students to identify alternative outcomes and conclusions. The next level of complexity is guided inquiry, in which the teacher poses the inquiry question and the students determine both procedures and solutions. The third, and most demanding, level is open inquiry. Here, the teacher merely provides the context for inquiry and students then identify and solve the problem.

Science educators constantly search for ways to encourage students to understand the dynamic and ever-changing nature of the scientific process (Zion et al., 2004). In recent years, more and more evidence indicates that structured and guided inquiry teaching processes, systematically guiding the student to solve predetermined questions, are not sufficient in developing critical scientific thinking. Because the purpose of inquiry teaching is to lead students to construct their own knowledge, and because questioning is an important skill, engaging students in an open inquiry process is considered an important challenge.

Teachers play a critical role in open inquiry learning. Their role incorporates guiding, focusing, challenging, and encouraging students to engage in this type of learning. The shift from facilitating students in structured inquiry to open inquiry is a challenging endeavor for teachers. In open-ended experimentation, students may have difficulty in choosing problems that can be translated into hands-on science experiments or solved with the time and resources available in school. A teacher who underestimates this difficulty may wind up with students who are confused and frustrated. In addition, science teachers experience difficulties in implementing the open-inquiry teaching approach. Teachers may feel a lack of confidence while facilitating students in the pedagogically risky process of open inquiry, in which results are unexpected, cannot be predetermined, and lead to additional investigations. The dynamic nature of the open inquiry process may cause teachers to feel overwhelmed by the student-teacher dynamics in their class.

We hypothesize that teachers who take a continuing education science course in which they learn scientific topics through inquiry are better equipped to understand the essence of the open scientific inquiry. We encouraged in-service biology teachers, coping with implementing a new open inquiry curriculum, to conduct an inquiry process similar to the one required by their students (Shedletzky & Zion, 2005). This research indicated that 8 in-service teachers improved their ability in three crucial areas: pinpointing inquiry topics, formulating precise questions, and organizing clusters of logically related questions. The participating teachers' primary efforts focused on formulating inquiry questions. This inquiry stage required them to formulate logically related questions regarding an intriguing phenomenon. The stage in which the teacher formulated the inquiry questions also required a precise definition of variables. We realized that teachers experienced difficulties in coping with vagueness and uncertainty, which are elements of the open inquiry process. Teachers preferred to select both trivial topics and questions whose results were known prior to conducting the investigation. Teachers also tended to formulate a list of logically unrelated questions that were connected nevertheless to a main topic. This thinking on the part of the teachers led them to shift the inquiry process from open to structured inquiry. We realized that feedback from the project coordinator, and from colleagues and teachers' own reflections, helped minimize the shift to structured inquiry.

During the practical open inquiry course for teachers, both teachers’ and their students’ similar difficulties in performing an open inquiry-based autonomous project could be effectively identified and monitored. Furthermore, both the participating teachers themselves and science educators who analyzed teachers' inquiry performances were ideally suited to formulate suggestions for overcoming difficulties in the open inquiry teaching process. We identify here four common difficulties and potential solutions that emerged in the continuing education course:

Difficulty 1. Identifying a curious and challenging phenomenon that may serve as a basis for inquiry questions. *Solution*: By exploring the nearby environment, the teacher encourages the students to record every phenomenon they encounter, including trivial ones.

Difficulty 2. Organizing an inquiry design of several logically related questions. *Solution*: Explain how the questions relate to the intriguing phenomenon observed in the field. Write an inquiry proposal containing the questions with which the inquiry process begins. The proposal should include the scientific-theoretical basis for the questions. Ask colleagues--teachers and/or students--to review the inquiry proposal. Later, students can organize their inquiry stages in a flowchart, emphasizing the inquiry plan and the logical relation between its components. It is important for students to keep a record of their reflections of the inquiry process.

Difficulty 3. Leading an open inquiry process that changes throughout the process due to technical problems or unexpected results. *Solution*: Advise teachers to experience scientist-supported open inquiry activities. In addition, active on-line forums operated by a center for science education can also be of great help in offering content and procedural information. In their respective forums, students and teachers can raise content-related or procedural learning and teaching difficulties.

Difficulty 4. The student (or teacher) lacking, or exhibiting, weaknesses in developing skills of asking inquiry questions, isolating experimental variables, and locating scientific information to support the learning process. *Solution*: Organize designated workshops (for students and teachers) in which students and teachers can present and practice inquiry skills.

Implementing a curriculum that emphasizes open inquiry requires several levels of consideration. We recommend that teachers receive training in an open inquiry process during the first stage of their pre-service program, and receive additional practical training throughout their career. We also suggest that curriculum developers construct a supporting platform for teachers and students using the expertise of scientists and teacher colleagues. This platform would help establish a learning community designed to encourage the confidence, and supply the pedagogical tools, needed to advance the important and complex educational process of open inquiry.

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Teachers' Understanding of the Nature and Purpose of Practical Work

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This research (Pekmez, Johnson, & Gott, 2005) represents the findings of English teachers' views on the nature and purpose of practical work in the context of the National Curriculum for science. Practical work has played a pivotal role in English schools through history. It serves many aims that help students formulate, and revise, scientific explorations using logic and evidence. In this study, the focus is on investigative activities that have been an established part of the curriculum since 1989. Investigations take a significant role as an enquiry approach to science education that is considered by many science educators to present a more precious and authentic experience of science (e.g., Minstrell & van Zee, 2000). While many studies have focussed on the role of practical work in science teaching (e.g., Gott & Duggan, 1995; Hodson, 1990, 1996; Hofstein & Lunetta, 2004; Lazorawitz & Tamir, 1994; Wellington, 1998; Woolnough & Allsop, 1985), teachers' understanding of its nature and purpose has been an issue of few systematic studies (e.g., Kerr, 1964; Wilkinson & Ward, 1997). For example, Kerr's study reported that teachers considered the most important purposes of practical work were to encourage students to make accurate observations, promote scientific thinking, and arrive at principles by investigations. However, the findings also stated that teachers rarely, or never, used investigative projects. Hodson (1996) identified three successive movements that have had an effect on practical work in both the UK and US: discovery learning, a process approach, and constructivism. For the UK, investigations must be added to this sequence.

Discovery learning encompassed the idea that pupils should find things out for themselves, thus developing their thinking. However, another viewpoint held that it would be unrealistic to expect pupils to discover things for themselves, since pupils' observations depended on their theoretical knowledge. In the process approach, the focus was on the methodology of science itself. This approach sought to identify what scientists do when they are being scientists and argued that this is what should be taught. The counter argument this time was that scientific methodology was not something that could be taught independently of content, since observation is theory-led. Therefore, science processes could not be carried out without theoretical knowledge.

Constructivism might go no further than exposing pupils' ideas, and its influence on teachers' views of practical work has been negligible. Finally, the inclusion of investigations in the English National Curriculum represented a move towards a more holistic conception of practical work (Woolnough, 1991). The main aspects of the 1995 specification for pupils aged 14 to 16 years are planning experimental procedures, obtaining evidence, analysing and evaluating evidence, and drawing conclusions. The difference between the process approach and investigations is that pupils should be thinking about what lies behind what they are doing rather than simply applying a practised process. This was called thinking behind the doing of science, or concepts of evidence (Gott & Duggan, 1995). These ideas represent a distinct conceptual content area of procedural understanding that needs to be recognised as operating alongside the more familiar content of substantive understanding in science. These ideas also allow for the assessment of the quality of investigations. In any problem-solving situation, a scientist will create a synthesis that draws on both substantive understanding and procedural understanding. This is summarised in Figure 1.

The aim of this study, then, was to explore whether the induction of investigations had brought about a new kind of thinking towards practical work amongst teachers. To what extent have the approaches discussed above taken root in the culture of school science?

The data were collected from a sample of 24 science teachers (one teacher in each subject area in each school) from eight participating schools. The ratio of male to female was 67% to 33% respectively, and 58% of the teachers had more than 10 years experience. The main instrument for data collection was a structured, individual interview. The interview included three progressive stages: open ended questions about both the aims of practical work and awareness of different types of practical work, with the final stage comprising probing questions using particular practical tasks in each teacher's subject area. A set of very common practical activities, of the four main types of practical work--namely skill, demonstration, illustration, and investigation, based on Gott & Duggan, 1995)--in the 11- to 16-year-old curriculum in each subject, was chosen.

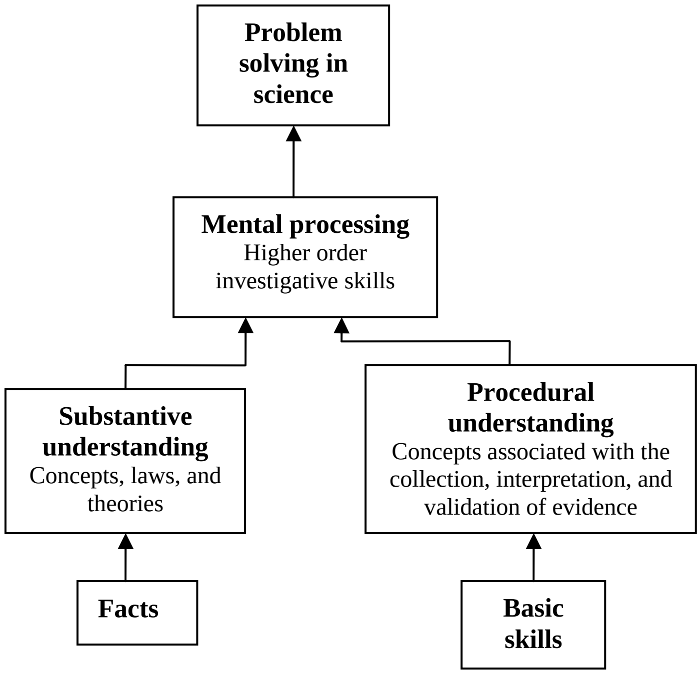

Figure 1. A performance model of scientific investigations (based on Gott & Duggan, 1995).

The main sense of what was said by each teacher was rephrased in a few words, and these words were then grouped into simple categories. In terms of concepts of evidence, five main areas of procedural understanding were identified, and these were used in a further categorisation of responses. These areas are:

1. *Variable structure*. This is related to the identification of the key variables of the experiment and the idea of fair testing.
2. *Decisions and trials*. After the identification of the variables, decisions must be taken about the measurements (range and interval) and the instruments (sensitivity, accuracy, and repeatability).
3. *Reliability of the data*. Monitoring the reliability of all experiments, by repeating measurements, is of vital importance in the continual process of assessing errors.
4. *Sampling*, which refers to the subjects of an experiment.
5. *Presenting data*, involving the use of tables and different graph types. The use of patterns to express relationships, as part of conclusions, is also important.

The following results are presented in three sections, corresponding to the three stages of questioning.

Stage 1: Purposes of practical work. The responses were grouped into four categories, as shown in Table 1. These data show that the most common thought of teachers about the aims of practical work is that it reinforces theory.

Stage 2: Types of practical work. Although the overall incidence was again low, in this stage more of the teachers started to emphasise procedural understanding.

Stage 3: Interviews about instances. In this stage, four common experiments from their particular subject areas were presented to the teachers. With the exception of investigative experiments, substantive ideas had a more significant role in the thinking of the teachers. Some responses relating to procedural understanding in Stages 2 and 3 are shown in Table 2.

Table 1
Teachers' Explanations for Purposes of Practical Work

Category	Common response	No. of teachers
Substantive ideas	Practical work helps understanding and visualisation of theory, and cements knowledge.	20
Motivation	Practical work makes pupils interested and motivated.	7
Procedural ideas	Practical work helps children to learn and develop skills such as manipulating instruments, reading graphs, and using a table to present data.	10
Communication	Practical work helps pupils to learn how to work, in groups, as a team.	2

Table 2
Teachers' responses relating to procedural understanding at Stages 2 and 3

Area of procedural understanding	No. of teachers	
	Stage 2	Stage 3 (investigative type)
Variable structure	8	12
Decisions	4	9
Reliability	4	6
Sampling	0	0
Presenting	5	4

Based on the quality of their responses, the teachers were placed into one of three groups. Group 1 teachers were those whose responses covered details and explanations of procedural knowledge. They can distinguish investigations as a type of practical work concerned with problem-solving. On the other hand, Group 3 teachers, who did not talk about procedural ideas at all, seemed to believe that practical work is a teaching method for supporting substantive ideas. They identify investigations as no more than a discovery method. Group 2 teachers, who were the majority of the sample, were consistent with an interpretation of investigations as "doing science." They seemed to believe that practical work is a teaching method to support skill development. This is similar to a process approach.

Almost a decade after investigations were mandated by the National Curriculum, it seems many teachers are not aware of content, comprising ideas about the quality of data, that should be taught. The reason is perhaps connected with the fact that the introduction of investigations with the National Curriculum has caused so much disquiet. Teachers can, and will, implement innovations effectively and efficiently only if they themselves recognise the need for change and the value of the changes being suggested to them (Dalin, 1995; Kelly, 1990). We would argue that consideration of the quality of data is equally important as the explanation of data. One needs to decide whether or not the data is good enough to establish that there is something to be explained. Otherwise, there is a danger that an investigation will be viewed as a re-run of discovery learning. Giving importance to the quality of scientific data, this study points to an urgent need for science teachers to develop a deeper understanding of procedural knowledge.

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Readers' Forum

Admit You Don't Know

As a full-time, seasoned, mentor teacher, I visit Grades 5-12 science classrooms every day. Several weeks ago, while observing a seventh-grade teacher, a teacher-student discussion was in progress with their astronomy unit. A student asked the question, "what is a light year?" The teacher responded: "It is the time it takes for sunlight to travel from the sun to the earth."

I felt like I had been hit by a bolt of lightning. After I regained some composure, my next immediate thought was "how can I turn this into a teachable moment for the students and not undermine the integrity of the instructor?"

So, I raised my hand and, once recognized by the second-year teacher, offered the following: "Yes, it does take time for sunlight to travel the distance from the sun to the earth. The distance is roughly about 96 million miles. Because light travels 186, 000 miles per second, it takes about 8 minutes for light to travel from the sun to the earth. But when we talk about a light year, we are talking about the distance that light travels in a given calendar year; or how far light travels in 365 days. So, a light year is a measurement of distance."

After the class was over, the teacher shared that he was shooting from the hip and wasn't too clear about a light year. We talked about the importance of sharing false information and how one would feel having learned something that was incorrect. We're far better off admitting to others, and ourselves, when we don't know something than falsely leading others to believe that we are correct in what we are saying. One of my favorite sayings is: "I've never met anyone who had all the answers to all the questions. Have you?"

Fortunately, from my observations, this is a rare occurrence. However, it does beg the question: "How often are our students receiving incorrect information?"

Eric Sensiba, Copernicus Science Project Teacher Support Center, USA

(*Editor*: A recent event supports Eric's view. During a science show dealing with electricity and lightning, we had developed the ideas that:

- It was safe to be inside a car during an electrical storm,
- Contrary to popular belief, the protection from a lightning strike that a car provides has nothing to do with the car having tyres,
- A car without tyres would be just as safe as one with tyres, and
- In any case, if one wanted rubber that would prevent lightning currents, the rubber would need to be a kilometre or so thick.

During question time, a puzzled student asked: "My mother told me that I would be protected from lightning as long as I had my rubber boots on. Is that correct?" We revised the ideas developed during the show and concluded that rubber boots would provide insufficient protection, to which the student responded: "Well how are we supposed to learn if we are told the wrong thing!")

Beliefs About Questioning

I totally agree with the Editor's comments re Brovey's beliefs on questioning ("Questions to Avoid," 2004). Rhetorical questioning and question-led lessons are valuable at all levels, and I use such particularly in my Years 11 and 12 Physics classes to engage the students, to get them thinking about things for themselves, and to develop their understanding, and interest in, the material. The following incident is a particularly good example, surprising me after more than 10 years of teaching.

Towards the end of one year (around reporting time, when Year 12 Submissions were due, and so on), I had to teach my Year 8 Science class without any preparation whatsoever. Now I have been teaching long enough for this to not be a particular problem, but I still normally manage to at least locate a page of a text that is relevant to the topic being covered! On this occasion, though, I hadn't even managed to do that, and entered the room with no idea of what I was going to do. So I fell into a questioning approach. The students were fairly new to the topic of Forces and Energy, and my initial questions led to a student-led question/answer session, which lasted the full 40 minutes. I can't recall my initial question, but it led me early on to ask the students to tell me what made a car move, and what forces were involved.

The responses included things like turning the key and using petrol. The discussion continued for some time and really engaged student's interest, as I kept saying: "Yes, and . . . .? There's something more significant!" We talked about how they managed to walk, whether they could walk in the same way on an ice-skating rink, and so on. After 15-20 minutes, we eventually reached the point where they managed to come up with the idea (following a number of leading questions) that friction was involved, and finally that the friction between the road and the tyres was what actually made the car move. Then we got onto action-reaction forces, "if you hit your head on the wall, doesn't the wall hit your head back?" and talked about rockets, etc., and the lesson became a class discussion on all sorts of issues that emanated from the students and were answered by the students (sometimes eventually, after repeated questioning and encouragement by me). Note also that these were all girls, with whom you wouldn't associate, as much as boys, an interest in cars.

At the end of the lesson, I thought to myself: Well, that was fun! However, I also considered the fact that the students hadn't actually “done” anything and that maybe it wasn't really such a good lesson. However, as the students slowly left the classroom, 3 or 4 of them came up to me and offered the following comments and others like them: "Can we have more lessons like this?" "That was the best science lesson I've ever had" (from a student who was bright but not particularly enjoying science." I had to admit, too, that the whole class was quiet and focussed for the whole 40 minutes. Even the couple at the back, who normally tended to try to chat during class, were quiet.

This would never have happened had I prepared the lesson as I normally would and kept the students "active" in terms of spending a large proportion of the time doing experiments, writing up results, coming to conclusions, responding to written material, writing, reading, and the like that would be a more usual feature of my classes at the Years 8-9 level. I'm not suggesting that this approach can be used continuously in the classroom, but it is very clearly of value to students. This would definitely not have happened had I heard of, and followed, Brovey's ideas.

Tertia Hogan, St John Fisher College, Queensland, Australia

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The Burning Candle Question

It was pleasing to see the classic experiment, in which a candle floating on water is lit and covered with a glass, correctly explained in this journal (Eastwell, 2004). The water level rises to approximately 20% of the height of the glass, but it is a pity that even nowadays one finds popular science books for children incorrectly claiming this to be proof that air contains about 20% oxygen.

The incorrect, yet common, explanation overlooks a variable that accompanies the burning process: a change in temperature. Due to the process of burning wax, the temperature rises a few hundred degrees and the gas below the glass expands and leaves the glass in the form of bubbles, which can be observed. When there is no candlelight anymore, the gas cools and its volume decreases approximately 20%, which is the reason for the water level increasing.

Readers may be interested to know that it has been only during the past decade or so that experiments with a correct control of variables were suggested, as follows:

No heating. A less violent oxidation process, not accompanied by a significant temperature increase, was used. Wet iron fibers were glued at the bottom of a glass, which was then put upside-down in water. After a few days, the water level rose approximately 20% of the height of the glass. With the oxygen interacting with the iron during the oxidation process, this experiment clearly shows that the proportion of oxygen in the air is 20%.

Using pure oxygen. The candle was lit in a glass filled with pure oxygen, and the result was approximately the same. The rise of the water level was a bit more than 20%, but it rose higher within a number of hours after the experiment as the carbon dioxide slowly dissolved in the water.

No candle. The experiment was done without a candle. To model the situation with the burning candle, the air was simply heated. The water again rose 20%.

For further information, please see Caplan, Gerritsen, and Dell (1994) and Krnel and Glazar (2001).

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Mojca Cepic, University of Ljubljana, Slovenia

? ? ? ? ? Your Questions Answered ? ? ? ? ?

This section of *SER* responds to readers' queries, so please submit your question to The Editor at editor@ScienceEducationReview.com . Have that long-standing query resolved; hopefully!

Mistakes

May I please have examples of actions that have been taken, presumably on the basis of the best scientific knowledge and advice available at the time, that have turned out to be mistakes. (By a mistake, I don't mean simply controversial, but actions that are now widely accepted as being a mistake. I plan to use these to demonstrate to my students that they need not lack confidence in questioning proposed actions concerning socioscientific issues, even in cases where the action is being recommended by an apparent authority.)

Probably the most catastrophic mistake in science was the use of Thalidomide, a mild tranquilizer for pregnant women developed in the 1950's. Approved by the authorities (FDA, I presume), Thalidomide was issued to many pregnant women. What neither the pharmaceutical companies nor the authorities knew was that Thalidomide produced terrible deformities in the children born of women who took the "wonder tranquilizer." Thousands of boys and girls were born without arms or legs before this medicine was forbidden. Other examples of dangerous drugs abound, but none was so stupid as Thalidomide.

Juan M. Lleras, Children's Museum Bogotá, Colombia

Two of the most long-lasting mistakes in Chemistry came from the same person, Thomas Midgley, (Jr.). The first mistake was to add lead to gasoline to control knocking and improve car engine performance. We may never know how many people died, or were seriously affected, by lead poisoning due to this fuel additive.

The second mistake was to develop CFC's as a refrigerant. This mistake initially saved lives, due to the previous poor refrigerants used. Most families kept their ice box on the back porch to avoid being poisoned. CFC's were hailed as nothing short of life-saving. Of course, it was 50 years later that it was determined that CFCs break down ozone and, as a consequence, they have slowly been fazed out.

Amanda George, Orange Park High School, Orange Park, Florida United States

Cooperative Learning Techniques

What cooperative learning techniques are useful for ensuring that all students are engaged during collaborative inquiry? (*Editor*: This question relates to Item 6 of the Inquiry Classroom Management Checklist, pp. 27-29 of Volume 4.)

My favourite for cooperative learning is to assign roles within a group. This serves two purposes: individual accountability and group accountability.

For example, the Materials Manager in the group is responsible for gathering, distributing, and returning all materials, thus minimizing movement in the classroom. The Health and Safety Inspector is responsible for ensuring both laboratory and safety procedures are followed and that a proper clean-up of the lab area is completed. The Data Analysis Expert is responsible for recording inquiry data on behalf of the group. In terms of structuring individual accountability, each student subsequently completes their own analysis of results.

Heather Mace, University of Ottawa, Canada

The key to successful cooperative learning is student responsibility. In Chemistry, the student must be focused and actively engaged in the laboratory activity or the results can be disastrous. Following is what I use to maintain order and promote learning in a safe and orderly (really controlled chaos) environment.

The acronym is BIGS, and it stands for Boss, Intimidator, Gopher, and Scribe. These roles are assigned randomly (students pick from a beaker) and each role has certain responsibilities. I understand that you are asking about inquiry based learning, but there is really no difference (other than the creation of a lab technique) when I do inquiry or cookbook. Thus, the Boss is the only person who can handle the expensive equipment (e.g., electronic balance, hot plate). This person will weigh on my AP electronic balance when necessary. The boss keeps a checklist of equipment used, and by whom, and also assigns certain procedures contained in the lab. Only the boss can ask my questions from the group. The boss' documentation is given to me at the end of the period.

The Intimidator is the one who keeps order within the group and keeps noise to a minimum. The Intimidator keeps track of time, ensuring that the lab group moves through each procedure correctly. If I need to address a group regarding behavior, it is the Intimidator with whom I speak. A lack of control can cause the group to either lose points or not complete the lab.

The Gopher is the only person permitted to get chemicals or supplies (other than those "big item" materials handled by the boss). The gopher insures that the group handles the chemicals carefully and is in charge of making sure the workstation is cleaned and that all chemicals, lab baskets, and supplies are returned to their proper place or storage area.

The Scribe ensures that all calculations are written down, that each person has a copy of the data, and that a proper conclusion is reached. I have been using this method for over 15 years and have not had any problems with either student engagement or accountability.

Nancy R. Silvia, Mount Pleasant High School, Mt. Pleasant, NC, USA

Stocktaking Materials

What standard procedures might be used for students to get, and return, materials during inquiry activities, and what methods are effective for stocktaking materials, both at the beginning and the end? (*Editor*: This question relates to Items 17 & 18 of the Inquiry Classroom Management Checklist, pp. 27-29 of Volume 4.)

To reduce demands on the teacher associated with the release and retrieving of materials, assign 1 student from the class to act as a lab assistant, logging out (and in) materials to (from) a representative of each group. To avoid overcrowding, they serve on a one-at-a-time, first come-first served basis. *Andrea Flores, Negros Oriental State University, Bayawan City, Philippines*

I find the following useful:

- Have a checklist available of the equipment being used.
- Count identical items out and in.
- Have a standard number of similar items, for each set of equipment, in a labelled container.
- Appoint a monitor from each group, who is responsible for monitoring allocated equipment.

Students/groups could be responsible for ordering/organising their own equipment requirements, and the Laboratory Technician/Manager is an important resource person in this respect.

Noelene Wood, Ogilvie High School, Tasmania, Australia

For stocktaking materials, have each group representative sign before taking, and after returning, the group's materials. To ensure effective returns, tell students in advance that the exam/test papers of members of a group will not be returned to them if all borrowed materials are not returned. Penalties reflecting the condition of the materials can also be introduced.

Daniel Kosia

Maintaining Materials

What processes might I adopt for ensuring that students are accountable for keeping materials in good condition during inquiry activities? (*Editor*: This question relates to Item 19 of the Inquiry Classroom Management Checklist, pp. 27-29 of Volume 4.)

- Time needs to be allowed towards the end of the lesson for clean-up/packing up.
- Materials need to be packed away safely and neatly at the end of each lesson.
- Depending on the size of an item, students should only carry one item per hand.
- Items need to be placed away from the edges of tables/benches.
- Items should be cleaned/washed before storage.
- Students need to be regularly reminded about being aware of their environment, which is usually crowded with much movement, and look around before moving.
- Groups can maintain their own inventory as part of their assessment. (Reporting breakages/problems are acts of responsibility.)

A high level of maintenance contributes to a group's assessment.

Noelene Wood, Ogilvie High School, Tasmania, Australia

Classroom Rules

What set of rules might serve as at least a starting point for the inquiry classroom? (*Editor*: This question relates to Items 2 and 23 of the Inquiry Classroom Management Checklist, pp. 27-29 of Volume 4.)

I am a seventh-year science teacher in an inner-city middle school in Houston, Texas. Our student population is predominately African-American, but transitioning toward at least 25% Hispanic. Even so, the majority of the population is low socioeconomic status and we are a title one school.

I try to teach inquiry, and sometimes I'm successful. My students have an infinite amount of patience. They will wait until the next grading cycle, and beyond, to be told the answer. It is very much like pulling rocks from compacted clay with your bare hands; long, very painful, and not often successful.

My rules:

1. Don't touch the equipment until told to.
2. Any question is okay, as long as it pertains to the experiment.
3. Basic procedure is to "ask 3 before me."
4. If you don't write up the work, the discussion doesn't count.
5. If you find an error I have made, it is worth 5 points extra credit for the lab.

I don't feel overly successful, so these rules might not be the best ones.

George Morrison, Houston, Texas

A rule I think is important is that teachers need to approve the inquiry procedure before students begin, which helps make the inquiry effective. It may mean several revisions of students' experimental designs. Students should be required to think about variables and controls, measuring, and what possible outcomes might mean before they begin.

Each lab group drafts their inquiry on large (2-3 foot) whiteboards and shows me. The drafts contain a statement about the aim of the inquiry and a sketch of the set-up, and students orally explain their procedure, how they will graph their data, and what the outcomes might indicate. If it is well planned, the students continue. Usually, I catch a major flaw and have them revise their plan. The white boards can then be used when sharing results to the class.

Jackie Kane, St. Ursula Academy, Toledo, OH, USA

Safety is of paramount importance in any science classroom, but particularly so when students are doing inquiry, and especially if the inquiry is student-directed rather than teacher-directed (which involves more independence on the part of the student). At the beginning of the year, my students and I go through the rules required by the district. These are quite thorough, but the list is long and makes for dry reading. While students and parents dutifully sign the rules agreeing to comply, that is never sufficient since the teacher is ultimately responsible for accidents. No instructor believes that one lesson at the beginning of the year, no matter how many official looking documents are signed, can effectively cover a topic as important as safety.

I also begin the school year by showing students the type of equipment they can expect to use. Such familiarization precedes understanding, no matter what the lesson. The next important topic deals with making high quality observations, and rules about safety are imbedded in those activities.

One of the hardest habits for students to break is placing a beaker under their nose to take a whiff of its contents. To reinforce the importance of wafting, rather than whiffing, we often create a rap song that includes the dangers and possible consequences. I also provide repeated reminders.

As uncomfortable as they might be at times, students must wear goggles. We have a song for that as well, which students sing from their lab area if they are caught with their goggles down. This isn't meant either as a chastisement or castigation, and cannot be forced on individuals, but is usually something students comply with and as they sing, they remind peers of how important "fashion" eyewear is in the science lab. Besides, the goggles are usually color-coordinated with their aprons. Students can be removed from the lab area if consistently not wearing them. If the activities in which students are engaging are sufficiently intriguing, as they should be if science is taught properly, students will not want to run the risk of being removed for safety violations.

Never eating anything in the classroom, nor having hand-to-mouth contact of any kind, is just a good habit. I've engaged in many high quality activities that involve food which students cook or create and then consume following the activity, but nothing edible is ever created or consumed in the science classroom. Rather, we find another location for such lessons because even their teacher cannot violate safety rules. If we pretend that rules can be broken for "special" activities, or by "special" individuals, students may begin to look at the rules as negotiable.

Washing hands when beginning an activity, after getting anything on the hands, and before leaving the room is also important, but then this behavioral reinforcement is important in everyday life as well as in science. Individual cautions about handling certain chemicals need to be covered whenever those items are made available to students. Even when students are engaging in independent research, it is important that the other students know what kind of activities are being done and what materials are being used. Reviewing such information not only allows the teacher to review safety and keep others informed, but also keeps students interested in, and knowledgeable about, the activities and discoveries of their peers.

Each activity has its own set of important safety instructions and all of them need to be reviewed, repeated, reinforced, and enforced. I can rely on students to provide general, common sense rules such as not wandering about the room or handling someone else's experiment. We also make a list of the behaviors that would be both dangerous and annoying as a group of cooperating investigators. I guide students in the generation of consequences for individuals who do not comply, and students are much more cooperative about following both rules and consequences that they helped to create. This helps to provide an atmosphere of teamwork rather than authoritarianism.

Pamela Galus, Lothrop Science, Spanish, Technology Magnet Center, Omaha, NE, USA

Further Useful Resources

learningscience.org (http://www.learningscience.org/index.htm) Dedicated to sharing new and emerging learning tools for teaching science.

HbL: Hypothesis-based Learning (http://www.hbl4u.org/) A new paradigm in teaching science.

The Little Book of Experiments (http://www.planet-science.com/experiment) Use the *Download LBE* link to download a large number of demonstrations and experiments.

physics.org (http://www.physics.org) Provides relevant web resources, which may be tailored for age and knowledge level, to answer questions asked.

Scientist Biographies (http://nautilus.fis.uc.pt/st2.5/scenes-e/biog/biog.html) Brief biographies of 61 scientists.

World of Scientific Biography (http://scienceworld.wolfram.com/biography) Biographies that can be searched alphabetically, as well as by branch of science, gender/minority status, historical period, nationality, and prize winner.

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