Progressing science education: an integrative view of curriculum, pedagogy and assessment

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(第六届STEM 教育发展大会)

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Introduction

I would like to thank the conference organisers for inviting me to talk to you today.

My name is Dr Keith Taber. I undertook my undergraduate degree in chemistry, before preparing for secondary school teaching of chemistry and physics. After working in state schools I moved to a further education college where I mostly taught 16-19 year old students. I later joined the Faculty of Education at the University of Cambridge, where for a number of years I was heavily involved in the preparation of science graduates for entering the teaching profession. I am now Emeritus Professor of Science Education.I have been asked to talk to you today about some key issues relating to science education. My thoughts have been influenced by my work as a teacher, researcher and teacher educator in the English context, but these issues are core considerations for organising school teaching in any national context.

I will be discussing aspects of curriculum, that is what we should teach; aspects of assessment, that is how we find out what has been learned; and aspects of pedagogy - that is how we should teach. But these three themes are, of course, strongly linked, or at least they should be, and I will also be drawing attention to some of this linkage. The curriculum is sometimes thought of in terms of either a list of subjects to be taught and studied; or as a more detailed list of content to be addressed in classes.

Curriculum

However, the starting point for curriculum needs to be in terms of aims - that is, in terms of what we are seeking to achieve. Only once we have decided exactly what education is meant to achieve can we consider building a curriculum specification.So, we need to ask the question:

Why teach science?

That is, why expect young people to study science?

There are clearly a number of possible answers:

The economic imperative

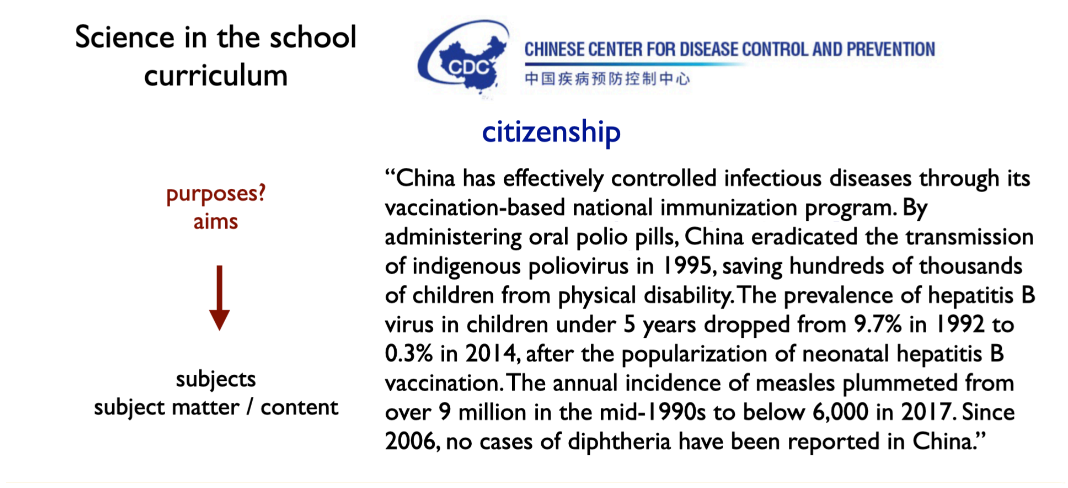
One answer is that society needs an educated workforce. We need scientists, and engineers, and medical doctors, and pharmacists, and so forth. We need scientists to work in industry. We need scientists to work in research. We need scientists involved in policy making, and in legal services. We need scientists who can teach the future generations of scientists.

Indeed, given the state the world is in, we need scientists who will make things better in the future. We need scientists who can respond to, or prevent, future epidemics. We need scientists that can develop more sustainable materials. We need scientists who can develop more energy efficient systems. We need scientists who can help stop and repair environmental degradation. We need scientists that can stop climate change. Perhaps we even need scientists who can help us move beyond this planet. To be honest, my personal view is that that last point is premature; and while so many people live in poverty and subject to unnecessary diseases, we would be better spending that money making earth a safer and more healthy place to live. However, in the extremely unlikely event that humanity is still around in another four billion years or so we will need to move on before the sun expands to engulf the planet!

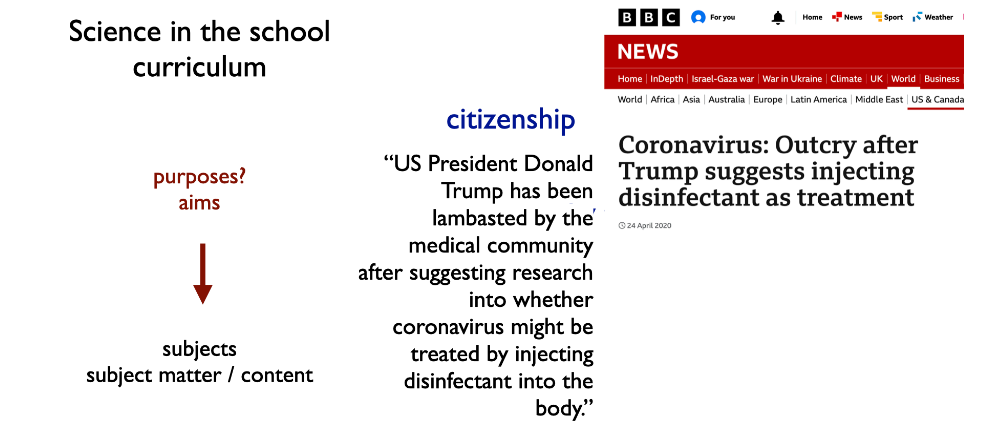
This economic imperative is very important, of course, but it is not the only reason to teach science. Now most of our young people are not going to end up as professional scientists, and that is just as well, as there are clearly many other important roles in society. But there is another reason for a society to want all its citizens to be educated in science.

Scientific literacy

We see the failure of scientific education in many parts of the world. Some very senior politicians in the United States claim that climate change is not real, and a great many of the citizens there are happy to accept that. In part this is a failure to understand the way science works, allowing an attitude that unless all scientists can agree exactly on the details of their models and predictions this must mean that science does not know yet. Yet science does not deal in absolutes, and waiting till all scientists exactly agree on details before accepting the gist of a theory, and taking necessary action, is ignorant. A similar thing is seen in so-called vaccine deniers who refuse to accept the evidence for the safety and effectiveness of vaccines that have saved millions of lives worldwide.



Like most advanced countries, China has achieved great things and saved many lives by its vaccination programmes. But vaccine programmes can only be effective to the extent they have uptake in the at-risk population. In some parts of the supposedly developed world we have seen the incidence of some controlled diseases rising because of scientific ignorance leading to people not vaccinating their children to protect them, and the community more generally, from dangerous illnesses.



As we have all recently seen, at a time of a global pandemic it is essential that people follow the best scientific advice, and this means that all people should have a basic understanding or, and trust in, science. And this also means that leaders themselves, although not usually scientists, must not be ignorant of basic science. The health of nations depends upon scientific education.

The cultural imperative

Another consideration. Education is partially at least about enculturation - about introducing young people to their culture. We tend to think of culture as being about art, dance, music, fashion, literature.

But science and technology are clearly also major features of modern technologically advanced societies. Just as no person should leave school without having learned something of great literature; no person today should be unaware of the nature of science, and the nature of technology, and of the critical roles these play in so many aspects of the modern world.

And it is important to also focus on the needs of the learners themselves: for surely education should support the development of the fully mature adult who is able to not only contribute to their local community, and wider society, but also to live a healthy, and fulfilled live. Education is about acquiring knowledge, but also skills, and values; and it is also about acquiring the confidence and self-belief to go out into the adult world boldly.

Learner aspirations

One aspect here is to allow young people to work towards aspirations. We have already considered how society needs scientists, but it is also important such roles are seen as open to learners form all parts of society. If someone wants to be a hospital doctor or an engineer or a biochemist then the school system should offer suitable support. We would probably agree that not every person could potentially be a good surgeon or an effective food technologist or material scientist: but we cannot make such discriminations at the age at which learners start school - so the system has to offer support for those with the potential and the willingness to work hard to follow a route towards higher education and a desired career.

I know that in my own country, England, we got this very wrong for several decades after the introduction of free secondary education for all, which was less than a Century ago. Bizarre as it may not seem, it was widely thought that an examination given one morning to all eleven year olds in primary schools across the country could identify the minority with potential to enter the professions or be senior managers and the like, and these were selected for an academic education. The rest, the vast majority, were sent to secondary schools with very different curriculums, where it was assumed the students were not capable of achieving such goals, and, so, where the structures were not in place to support any pupils with such aspirations.

It was eventually realised that selection was much more about home background and the greater number of out-of-school resources available to those from homes that were better aligned with academic and professional aspirations. Eventually the system was scrapped, at least in most of England, and replaced by comprehensive schools that welcomed all children in their local community, and recognised both that learners develop at different rates, and that pupils may have different levels of academic support at home.

Sadly this progressive move was somewhat undermined by a later shift to a market mentality which sees schools as competing for pupils and offering choice for parents, and which allows many schools some element of selection in which pupils they accept.

Sharing values

More generally, we want young people to grow up as happy, confident people, who can face challenges, solve problems, co-operate with others and work well in teams, show empathy and consideration and due respect to others, to communicate effectively whether that is about their feelings of their ideas, and so forth. The school curriculum needs to provide guidance and offer opportunities for learners to develop in these various ways. Some aspects will be best supported by certain subjects, some aspects will be cross-curricular, and some may even be primarily linked to what is sometimes called the hidden curriculum - the norms and procedures that offer implicit messages.

As an example of this, consider the laboratory rules for safe working that are needed to protect young people in a school laboratory. I an thinking of rules like using protective equipment such as safety spectacles to protect eyes

Probably the best way for the teacher to ensure the class has a strong set of rules to follow, is to write these rules herself and present them to the class. She is the expert, and she is the responsible adult, so this seems obvious.

However, sometimes teachers will engage in a process whereby children discuss their suggestions for what should be in the rules in small groups, then the teacher leads a class discussion that seeks to move towards a consensus list the class can agree on. Of course, a skilled teacher can shape the discussion and lead it in a preferred direction, but this may seem to be a less efficient and indeed somewhat risky approach.

A teacher may adopt such a procedure for pedagogic reasons, because children are more likely to remember rules they have thought about, and understand, and have had some role in shaping. There is also a sense of ownership in that breaking the rules is going against the communal class decisions, not just rules imposed from above.

But such an approach may also be considered to reflect an implicit value about how people should be involved in and contribute to communal decision-making - that is, it reflects a societal value that we might want children to learn, and which needs to be taught by example.

Personal development

This perhaps leads to my next point. Science can contribute to the development of the young person. An obvious area is logical thinking as science is based on a rational approach to understanding the world, based on evidence connected logically by argument, to support propositions, hypotheses, theories, laws and so forth. Science is often concerned with building arguments that are based on logical connections. So, for example, a key feature of science concerns developing explanations of the natural world.

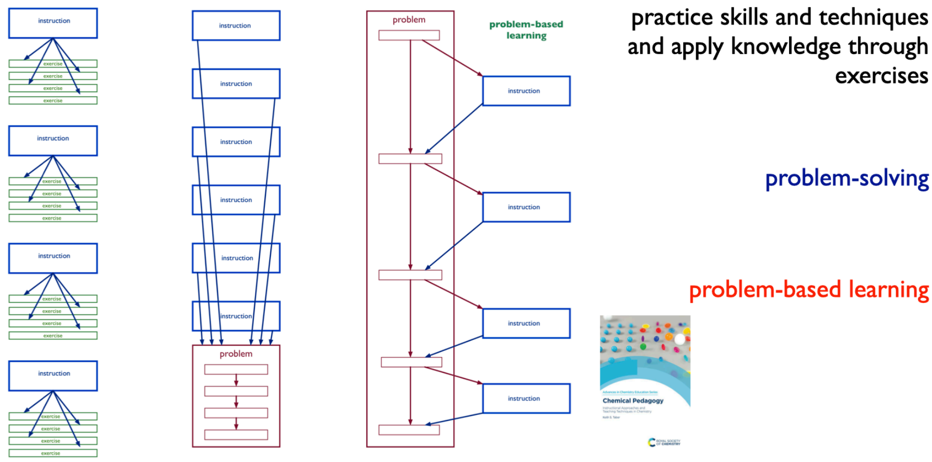
The practice of science itself is often about problem-solving. And this reminds us that science involves creative thinking as well as logical thinking. The later stages of the scientific process require logical deductions and connections, but this is only possible once there are ideas to test.

Science requires imagination, as when Albert Einstein imagined how a light beam would appear to a traveller moving alongside it at the speed of light - leading to the insight that resulted in Einstein developing his theory of special relativity. That is an extreme case, but science is fill of things that have to be imagined before they can be formalised in hypotheses for which tests can be designed. The atom, the electron, the gene, the quark, the Higgs boson, and black holes are just some examples.

Now here is an example of a link between curriculum and pedagogy. If we want learners to develop problem-solving skills, then they needs to have opportunities to developed such skills by regularly being faced with problems to solve. Traditionally, teaching has featured a good many activities that are better understood as exercises. The teacher teaches something new, and then the class work with this new idea or technique through a number of examples.

The teacher moves onto something else, and then the class work on a number of examples for this next focus. And so on. Learners know exactly what learning they are meant to apply.

By contrast, in problem-solving, learners are required to synthesise their responses to a task based on their prior learning, perhaps including some material studied some time before, and possibly bringing together ideas from different topics, or maybe even different subjects.

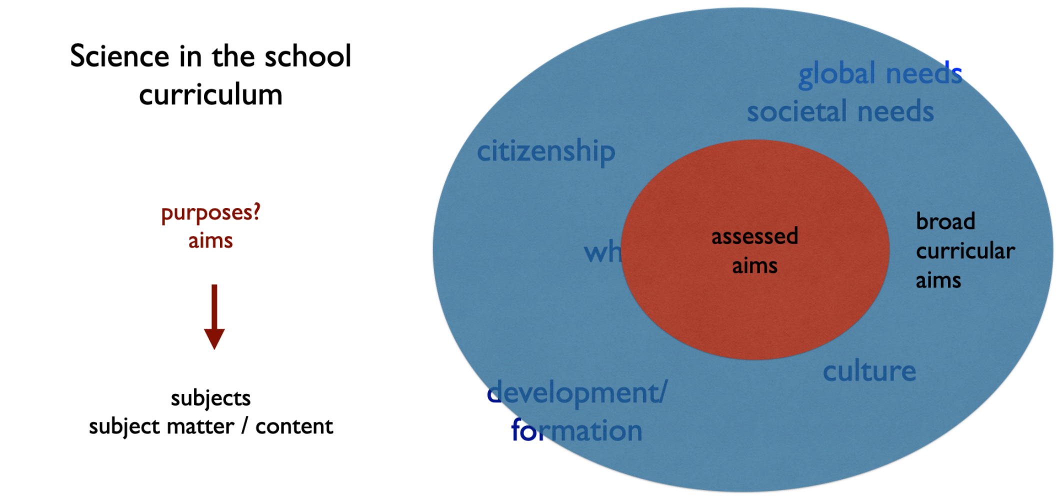


One step beyond problem-solving is problem-based learning, where the problem comes first, and learners are taught new material on a 'just in time' basis when it is needed as motivated by the project. This pedagogy is sometimes considered most suitable in higher education.

But just considering the distinction between setting learners exercises and problems, this could be left as a choice for the teacher in planning how to teach. Perhaps some teachers would feel problem-solving is important and wish to do some of their teaching in this mode. But if we think problem-solving is important enough that all students should regularly be given opportunities to engage in solving problems, then this needs to be explicit in curriculum specifications.

Teaching to the test?

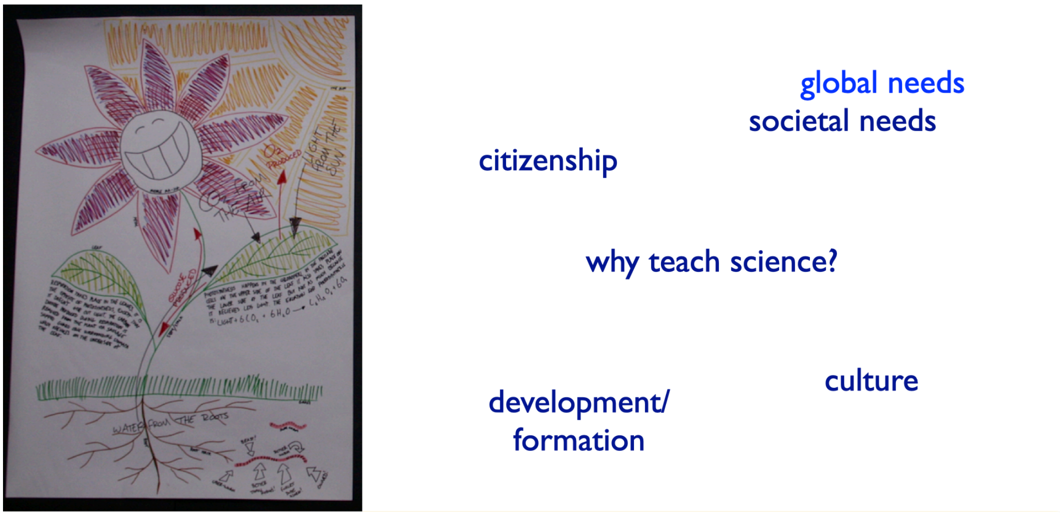
However, my experience in England, suggests that may not be enough. Even when such aims are specified, teachers often need to be shown how they can be related to specific subject matter content, and indeed to expect such an aim to be reflected in the formal assessments students will undertake. For reasons I am sure we can all appreciate, teaching tends to strongly reflect what teachers believe will be assessed in any final tests or exams, so if the examinations are set externally to the school, they need to clearly reflect the full range of curricular aims if we expect teaching and learning to reflect those aims.



Where there is a tendency to focus formal assessments on what can be assessed with most validity and reliability, then there is also a tendency for assessments that do not represent all we want education to achieve. Where examination results are critical for children and their teachers, we can understand why this means teaching will largely focus on what will be examined.

Curriculum-led assessment

The point is that if we only recognise the importance of developing logical thinking we would set up a curriculum and approach to teaching that supported learners in developing this feature, and an assessment system to test if this had been achieved. If we recognise the importance of the creative aspect of science as well, then this needs to be seen in our curriculum specifications, in our teaching, and in our assessments. So, for example, if we only value the logical skills there is little point in asking learners to devise their own representations and models for their ideas in science, as we have standard representations and models that are considered canonical, and which we want learners to acquire. But if we recognise that a key part of science is creative, then we recognise value in such activities, activities which reflect a key part of scientific practice.



We may also recognise the need to go beyond simple logical thought when we consider how rational argument is often insufficient for the application of science. Science is concerned with developing better understandings of the natural world. But the use of science in society involves other considerations - and our technology is designed to meet human needs. Science can tell us about what is needed to dam a river and form a new reservoir, and science can also tell us about the potential environmental impacts of this on wildlife. But science, of itself, cannot tell us whether it is right to build a particular dam. There might well be strong regional economic arguments in favour of the project, but with costs of displacing some people from their ancestral homes, and damaging the balance of nature in the local ecosystem. These are not questions for science alone, but they are questions that draw upon scientific knowledge and understanding and that must be addressed by people prepared by the education system to engage with the science.

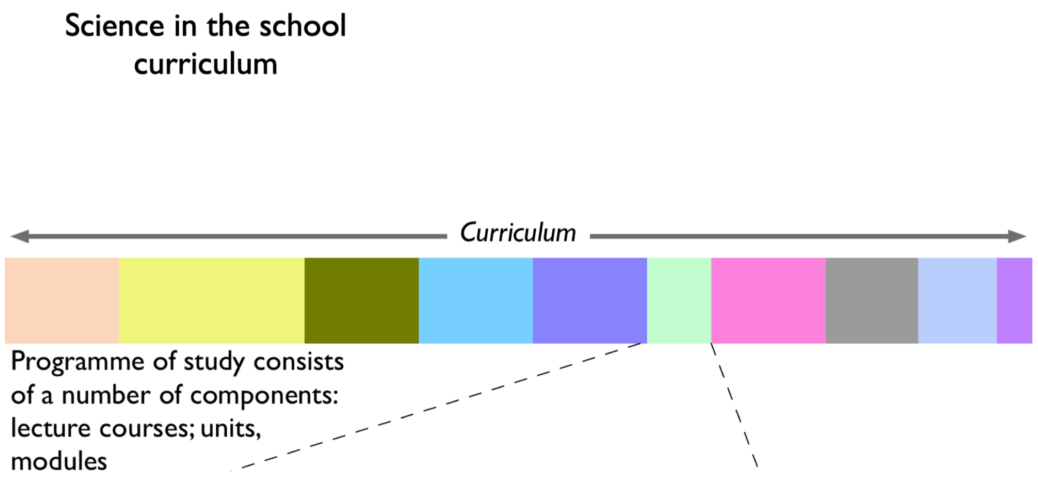
Perhaps this seems an extreme example, in that most people will never be directly involved in such policy decisions. So, consider a more personal example. Imagine a person who is told by their doctor that they have a terminal disease. Past experience suggests that a person with such a condition at this stage has only 6-9 months to live. The doctor can offer treatment that is likely to prolong life. As different patients respond differently, all that can be said is it is most likely to offer an extra 4-8 months. But treatment would require extended hospital stays, is difficult to tolerate, and has some unpleasant side effects: most people get nauseous, and get irritating itches on their skin. Science is offering information about disease prognosis, possible treatments and side effects, and so forth. But this 'objective' information cannot of itself be sufficient to guide a patient on the best route to take. That might depend on many factors, such as family situation, and personal values. It may be rational to seek to extend life or it may be more rational to minimise medical interventions during the time left. For a person to make a good decision, good for that person, they would need to understand the scientific information, including how the doctor can only offer guidance based on what is typical when patients will vary in their response to disease and treatments. But they would also need to combine this scientific understanding with other contextual and affective information.

Now the point is that while not everyone has to decide on building a dam, most of us will at sometime have to deal with medical ideas relating to ourselves or our family. People also have to make purchasing decisions and make decisions relating to their use of energy and other resources, and their recycling behaviours, and often these issues are best informed by a compounds of understanding the science behind claims (such as that some more expensive food is healthier?) in the light of personal goals and needs and personal values. So the question is what kind of science education can support young people into being able to deal with the many decisions they will face where science is relevant but not the only consideration?

A response to this has been the argument that school science needs to not only teach the science, but present learners with experiences where they need to apply the science in complex, messy scenarios that require balancing up different considerations and arguing for a position that can never be reached by logic alone. So the curriculum should include engaging with socioscientific issues, if it is to prepare young people for how they will experience science in real life situations.

Awe and wonder

Another important aspect of a science education relates to the so-called 'awe and wonder' responses to nature. We live in an incredibly complicated and sometimes very beautiful universe. Surely science education should reflect that and encourage this kind of response.



Defining the subject

While the process of setting a curriculum may be seen as discrete from the processes of teaching, in practice teaching is planned at different levels and scales, and there is s shift from the overall curriculum specification to the choreography of moves a teacher makes in the classroom.

Giving a subject such as science a place in the curriculum is just the start of a process.

First we have to decide what counts as science. This is more problematic in some subjects than others and generally people agree on what counts as science, or, say, chemistry, even if there are some disputes around the borders.

Once we agree what counts as science we need to select what to include in the curriculum. This is challenging because there is a vast range of possible material, and so it is essential to be selective.

There are two dangers here that it is easy to fall into. One is that if we worry too much about excluding things that might be useful, we risk including so many topics and concepts that so little time is available for each thing we want to include, and there is no time to do anything in depth. We have to ask whether it is more important to know a little about a lot, or understand some things deeply. A particular problem is that although new topics arise as science progresses we may be tempted to add them to the school curriculum whilst not wanting to remove anything which has been traditionally included.

The other danger is seeing the subject only in terms of its concepts and topics. Yet if we consider the broad range of aims our curriculum is supposed to address, we may think it is important to focus on science practices and processes - argumentation, explanation, hypothesis testing, problem solving and so forth - as much as topics.

Next we need to consider the age, educational level, and background knowledge of learners. Science is often complex, nuanced, technical, and sometimes highly mathematical. Often we need to produce a curriculum model of a scientific topic which simplifies the science so it retains the essential features of the professional account but is accessible to young learners.[1390+8=1388]

We then need to decide how to break up the subject into manageable units and modules.

Finally we need to determine a sensible order for presenting topics. This needs to reflect the logic of the subject, but also the age and readiness of different learners.

Science in the school curriculum

Planning teaching starts from the curriculum

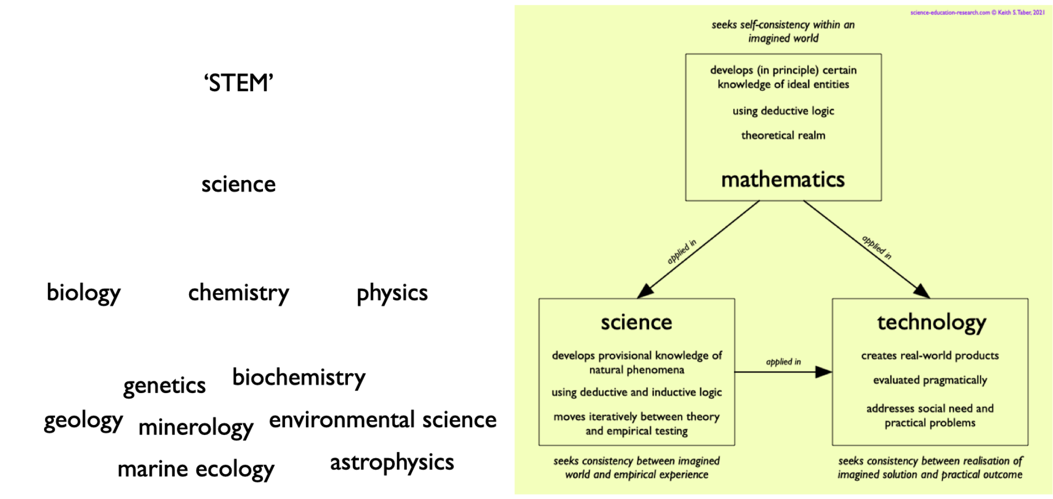
There is an overall process:

- scope
- select
- simplify
- segment
- sequence

This all assumes we can agree on what the subject is.

The 'STEM' question and the place of science disciplines

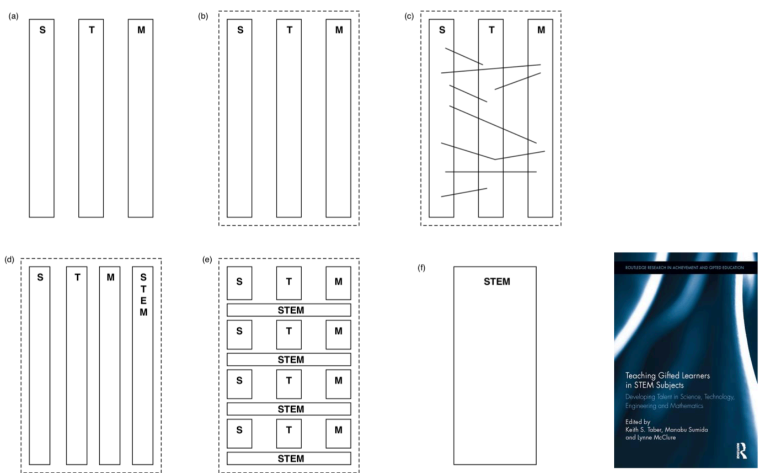
In the real world problems are often solved by cross-disciplinary or interdisciplinary teams - but these still need specialists. We do not want learners to compartmentalise subjects into discrete boxes without linking between them. But science is very different in some ways from say mathematics or from technology.



And within science there are many discrete disciplines each with their own flavours.

So, there are good arguments to develop links across STEM, but also good reasons to want learners to experience and appreciate science as a subject alongside but distinct from other curriculum areas, and even to be given opportunities to study and discriminate between the different science disciplines.

There are many ways schools can respond to this challenge, without simply merging science, technology and mathematics within one curriculum subject.



This likely needs to go beyond simply locating these subjects within a single department or directorate, to at least having some planned and explicit links built into teaching schemes.

One option might to have STEM as a parallel subject, but a more productive approach would be to have regular sessions where the the normal timetable gives way to STEM sessions that draw upon what has been taught in the different curriculum subjects, perhaps in the form of inter-disciplinary projects.

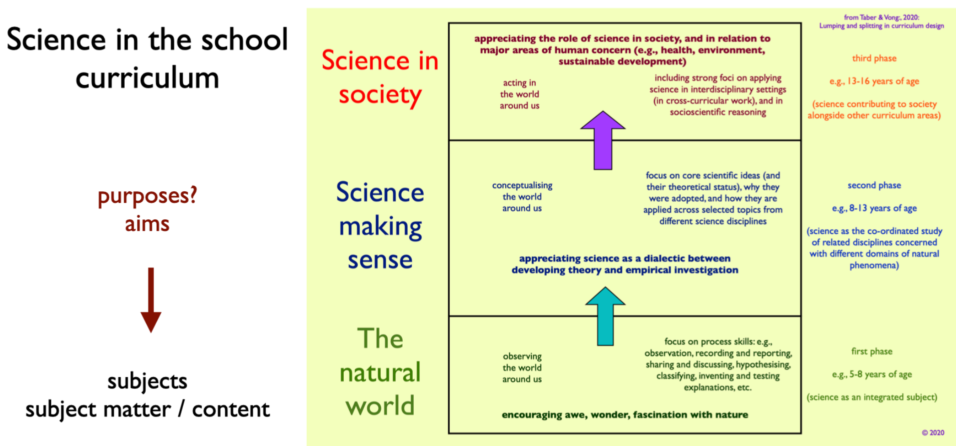
Teaching according to developmental level

It may seem impossible to devise curriculum and teaching to meet all our priorities, and certainly some compromises will be needed.

But we should be aware that what is most suitable will likely change as pupils grow and develop. So in early years, where often teachers are not science specialists and may not be over confident in all areas of subject knowledge, it may make sense to focus on developing scientific process skills and attitudes with a particular concern for observing, and conjecturing about, the natural world.

More abstract theoretical concepts can be introduced later, when learners have developed further cognitively.

Older learners will be ready to apply ideas across disciplines and to engage with science in complex real-world scenarios.

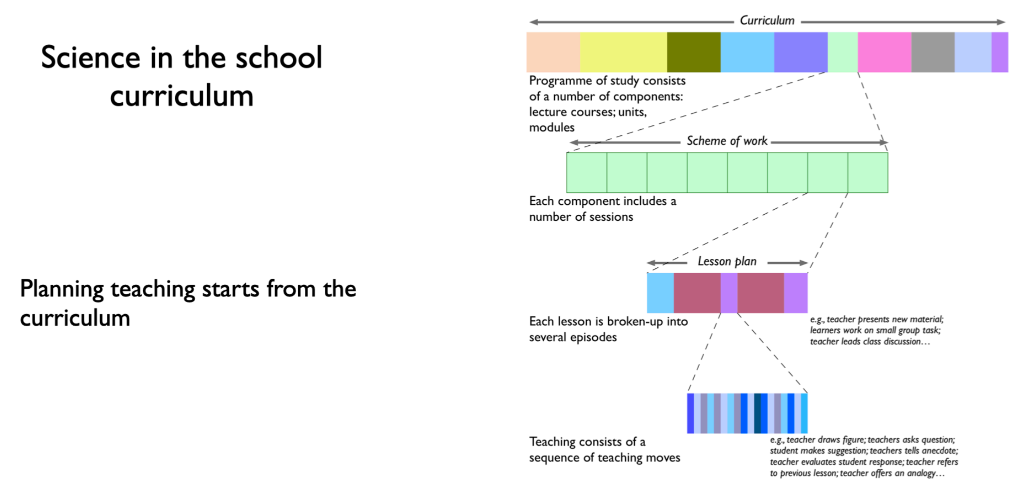


Constructing learning

If we take into account the findings from research into human learning, then we know that learning is incremental, interpretive and iterative. Learning is incremental because the cognitive apparatus known as working memory has a very limited capacity for new information, so learners can only deal with modest learning quanta of new material in any lesson. We also know that making sense of teaching largely relies on relating what is presented by the teacher to existing prior learning - the students' existing knowledge and understanding. So teaching needs to connect with what has already been learned. This makes learning iterative, in that when a person has a strongly established way of thinking about things they tend to interpret new information accordingly and understand it fit with their existing ideas. That can be helpful when students have a strong background knowledge, but may be problematic if they have alternative ways of thinking, so called 'misconceptions'.

We also know, that usually learners only form long-term stable memories of what they have been taught when it is understood well at the time, and there has been adequate opportunity to practice using the ideas, including regular reinforcement opportunities after initial learning - as memory consolidation is a process that takes place after the initial learning.

This means that converting a curriculum into an effective teaching scheme has several levels of structure.

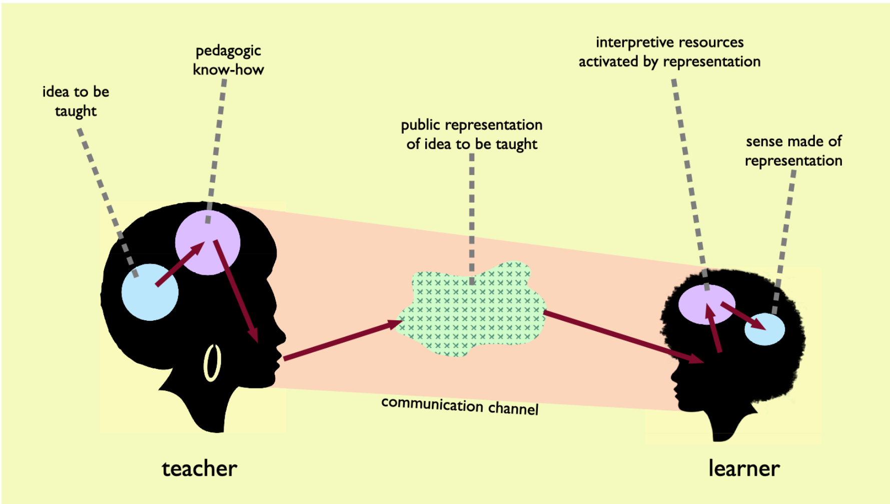


Topics need to be introduced in logical order in terms of the subject itself, so that more advanced topics that draw upon ideas from more fundamental topics are only met after the more basic topics. But also taking into account learners readiness at different stages - so we adopt a spiral curriculum where topics are met in stages over several educational grades. However, we also need to build in a good many opportunities to link today's teaching back to earlier topics in order to reinforce past teaching so that learners will retain their learning over the longer term.

Experienced teachers are well aware what commonly happens when teaching that seems to have been effective at the time is not sufficiently reinforced in later classes.

Learning is interpretive

One of the most powerful shifts in science education came with the realisation that teaching could not be seen as an automatic copying of ideas from the teacher's mind to the students' minds. Certainly with complex, abstract, conceptual material, as is common in science, even the most careful, accurate and clear presentation given to attentive, well-motivated learners is not sufficient to ensure understanding and later recall.

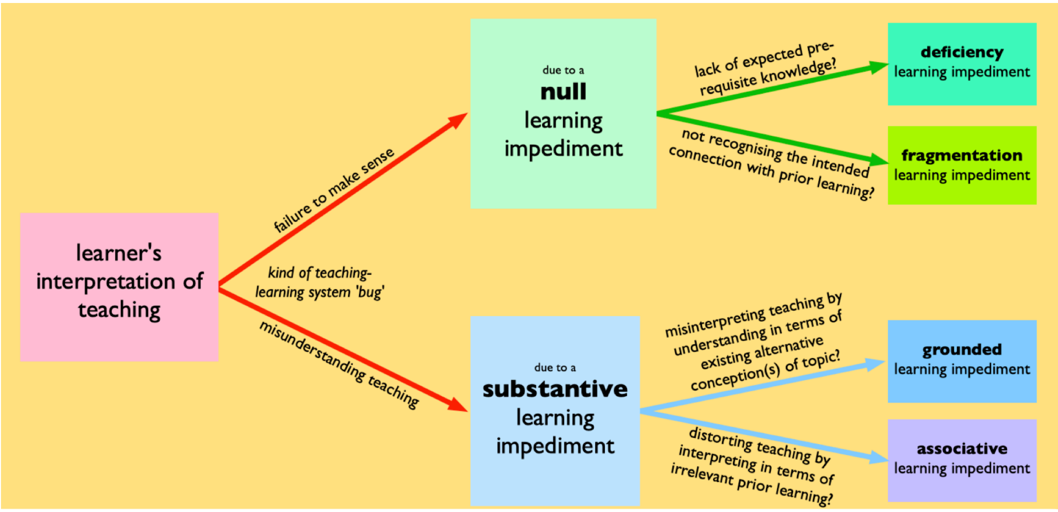


Rather, learners have to make sense of teaching by interpreting the public representations produced by the teacher, her words, her notes on the board, her gestures and so forth, in terms of each learners' unique repertoire of available interpretive resources based on their prior learning and experiences.

What the learner already thinks is a key factor in how teaching is understood. And learners do not come to classes as empty minds, but with a wide range of existing notions which are more or less aligned with what they are meant to be taught.

Misconceiving teaching

Sometimes learners simply do not make good sense of teaching.

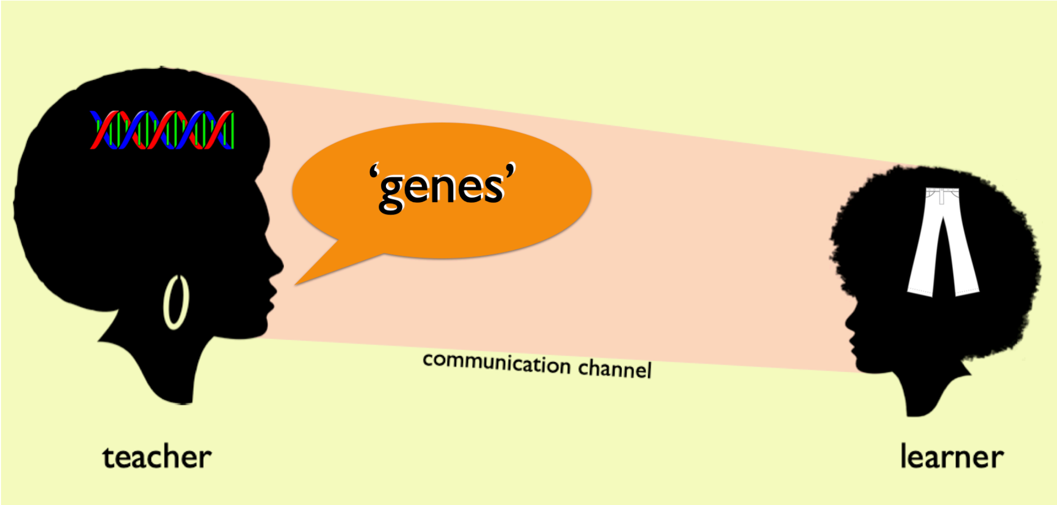


This might be because they are missing some prerequisite learning expected by the teacher; or it may be that the student simply does not make the necessary link between teaching and prior learning.

But it is also possible that learners do make sense of teaching, but unfortunately misunderstand and form a different meaning to that intended.

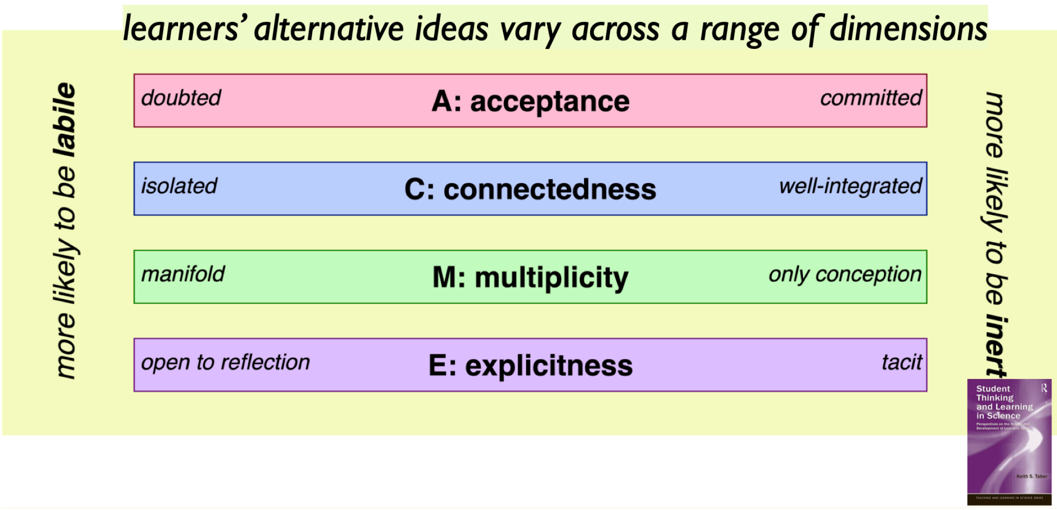
This might be because of an existing alternative conception - some pre-existing notion that is at odds with canonical science.

Or because teaching is understood by being linked to some existing prior knowledge that from the teacher's perspective is irrelevant and unrelated. Such links tend to be unhelpful and may lead to new misconceptions.



Alternative conceptions

From the 1970s onwards, extensive research showed that school age learners tends to have ideas relating to all areas of science which were somewhat, or sometimes completely, inconsistent with the science to be taught.

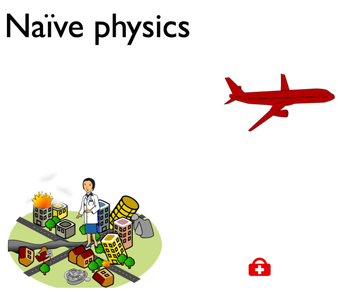


These ideas varied in many ways. Sometimes they were strongly believed by learners which made them resistant to change. Sometimes learners' misconceptions were embedded within extensive networks of ideas, which made them difficult to challenge. Sometimes learners did not already hold explicit misconceptions, but had intuitive ideas about the world which influenced ow they interpreted and understood teaching. In chemistry, for example, there are widespread common alternative conceptions relating to atoms and molecules even though learners will usually only meet these ideas in their school science.

A great many misconceptions have been reported, some of them being very widespread.

It has been found in many studies in different parts of the world that the vast majority of learners already hold notions about force and motions that are inconsistent with physics, but which tend to be resistant to being changed by teaching.

The principle of inertia, a core part of the physics of Isaac Newton, seems counter-intuitive to many learners who tend to associate movement with a force acting, when physics associated acceleration, a change of motion, with force.



Learners' ideas often have their own logic, so teachers cannot simply replace them by teaching the correct science - rather, often learners need to be persuaded that the unfamiliar scientific idea has more merits than a sometimes long-held notions that make good sense to the student.

Metals do not boil - or freeze

what do you think would happen if I heated the iron liquid?

"It would stay a liquid."

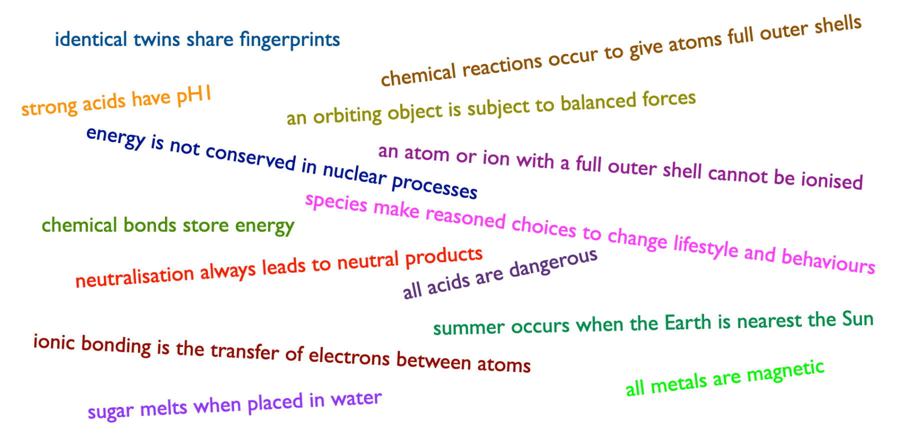
12 year old

"well this sounds like ridiculous but, like but before today like none of the people in out class had thought about iron being turned into a gas, and it's little things like that which sound weird"

16 year old

Casting cooper into bars [**copper freezing**]
(Kodō Zuroku. Illustrated Book on the Smelting of Copper, 1801)

Even though metalworking has been known since antiquity, students may take some persuading that something as solid as a metal could ever boil, no matter how hot it gets; and they may not see the solidification of molten metal as being an example of freezing as it happens at a high temperature, where (in English at least) the term 'freezing' is associated in everyday life with very low temperatures.



There are a great many more examples I could discuss, but the key point is that we now appreciate that effective teaching is not just about how the subject matter is broken down, sequenced, simplified and presented - but also about how learners will make sense of it, given their existing ideas

Teaching requires a mental model of the learner

This means that effective teaching requires the teacher to think about how learners will make sense of teaching in terms of the resources they have available to interpret what they hear and see. And, of course, every student in a class is unique with their own idiosyncratic set of resources for making sense of teaching. There are many teaching techniques or approaches which take into account learners' thinking, and which may be collectively labelled constructivist techniques. I want to simply examine one example known as jigsaw learning.

A constructivist teaching approach

Let us imagine that the class are to learn about different groups of vertebrates, or the properties and uses of different metals. The teacher starts by dividing the class into different seminar groups that will study together by each member of the group teaching the others about one example. So perhaps one learner in each group will be the expert on reptiles, and another on birds, and so forth; or one will be the tutor for magnesium, and another for copper, and so on. Of course, there is a problem here, in that the learners are students, and so are not the experts.

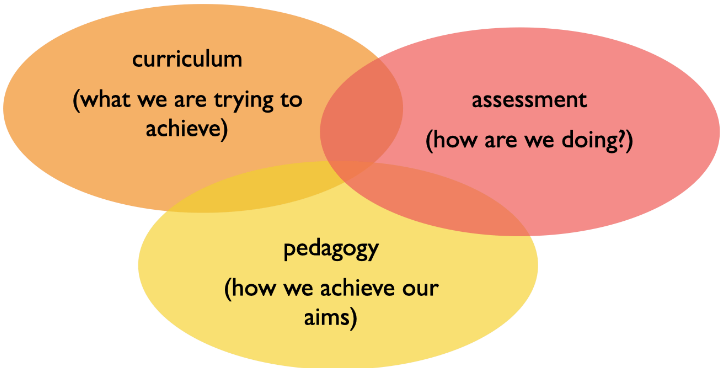
So first the tutors have to learn about their subject. The students are rearranged into expert groups, all the mammals tutors in one group, all the reptiles tutors in another and so forth. Each group is given the resources to learn about their assigned topic, and to plan a short teaching input for other students. Then all the student move back into their seminar groups where each member of the group teaches the rest about their assigned topic.

Now this is a very complex basis for a lesson, which requires the teacher to provide resources that can allow students to become expert enough to teach each other.

As the teacher is the real expert, and many students may struggle with the challenge of the task, it would have been a lot easier and more effective for the teacher to simply present the material to the whole class. Certainly there is much scope for the jigsaw approach to go wrong!

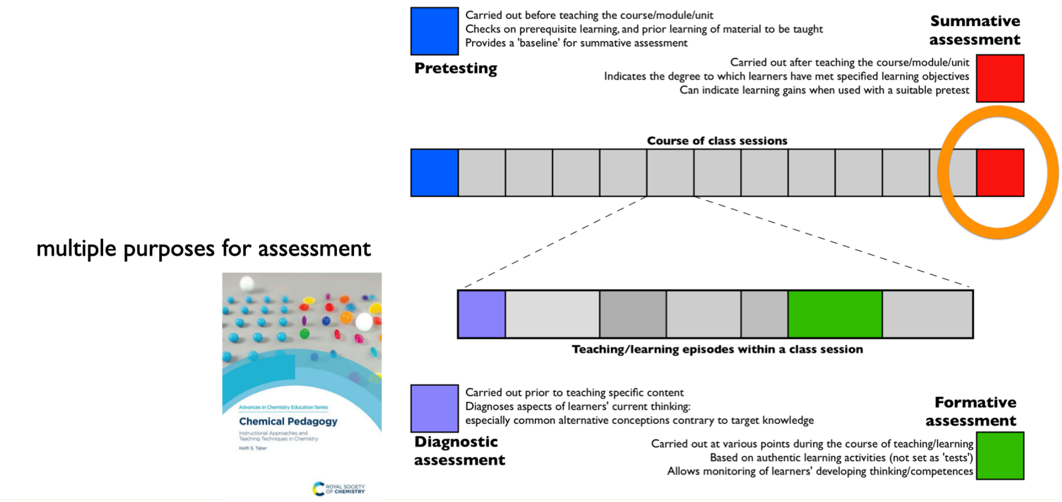
So why is this technique being recommended?In part this is because of what we have learned about cognition, and the need for learners to actively engage with material in meaningful tasks. There is a limit to what most young people can learn simply by listening to a teacher - even a good teacher who has prepared well. Engaging in dialogue, discussing and talking over ideas, is an important part of bringing about effective learning. However, a teacher might use this approach on occasions because our curriculum aims are not just about learning subject matter, but are also related to such matters are team work, planning and communications skills - and this kind of activity offers opportunities to develop these skills. Needless to say, a wise teacher will choose a focus for such an activity which allows these aspects of the curriculum to be enacted, without compromising core subject knowledge.

So, perhaps if students have already been taught about the nature of metals, and the different properties that metals usually have: conductivity, malleability, ductility, sonority, lustre and so forth, a followup lesson would be based on exploring how the specific properties of different metals lead to their common applications, this reinforcing earlier teaching and using jigsaw teaching where any errors of detail are less critical. Given our multiple and complex curriculum aims, and the limited time teacher have with any particular class, teaching always involves some compromises. So, one aspect of taking science education forward is the need to see how curriculum and pedagogy or instruction need to be strongly linked together.



Forms of assessment

And the same is true for assessment. We normally associate assessment with tests that are designed to see if learners have learnt what has been taught. These so-called summative assessments may be used for awarding qualifications, making decisions about progression to further education, and may also be used as a means to evaluate teachers and schools.



But in recent years attention have been given to wider forms of assessment intended to support the teaching and learning processes.Pre-tests may be used at the start of courses. These can offer some means to judge progress when compared with final tests, but they also offer support for teachers. Most courses assume learners begin with certain prerequisite knowledge on which they will build - but this may be missing. So a pretest can check for this, allowing teachers to take any indicated remedial action. Pretests can also check that learners have not already mastered the material to be taught, as if so the teacher can organise class time more effectively than simply repeating what has already been learnt.

The term formative assessment is used for activities which are designed to give the teacher, and so by feedback the learners, information of how much they have learned to date. Formative feedback is used while teaching still proceeds, while there are still opportunities for teacher and student to respond, rather than waiting till a final summative assessment. It is recommended that formative feedback should be focused on offering qualitative guidance on strengths and weaknesses, rather than providing scores or grades.

Earlier I referred to the vast research showing that learners commonly come to class with alternative conceptions inconsistent with what they are to learn in science. Diagnostic assessment refers to activities drawing upon this research to check whether learners hold common misconceptions. For example, activities can be designed that require learners to discuss topics, to reveal whether they hold known common misconceptions. This concept cartoon represents a scientific perspective as well as three common alternative conceptions. Learners can discuss the cartoon in small groups, offering the teacher insight into their thinking.

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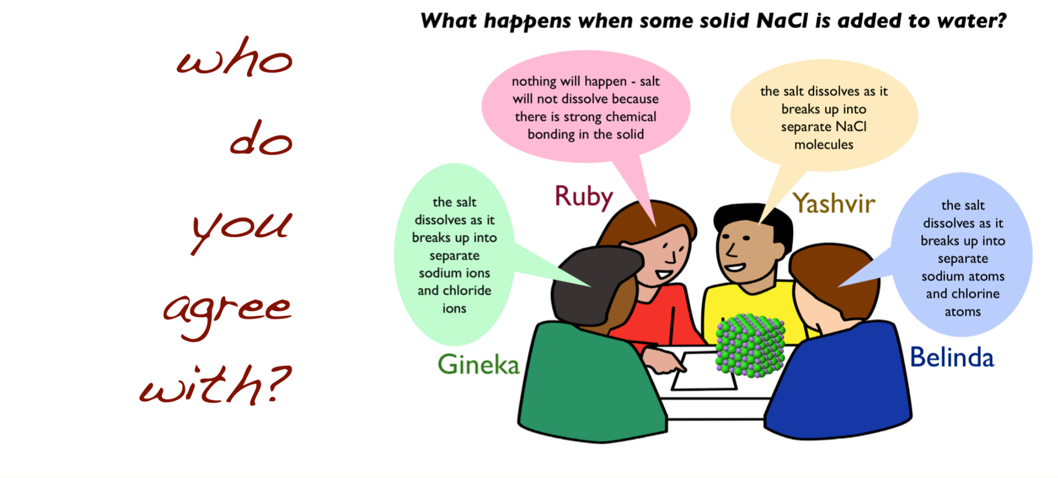

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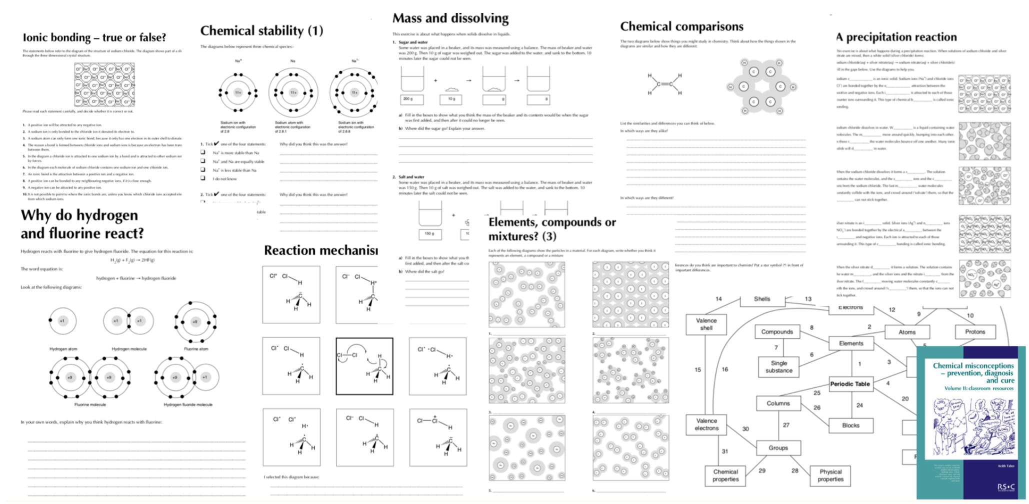

To conclude:

I think we can identify a few important trends in science education that will help us provide a better education for our students. One of these is a need to see curriculum as much more than a list of topics. Science education needs to reflect the nature of science, and the processes of science, and the way science can inform both policy making and individual decision-making. Such a science education better supports both those learners who will go into science-based careers, and the majority who will find science and technology impacting on many aspects of their everyday lives. The broad aims of our science curriculum also contribute to the overall development of the young person in aspects such as team-work, communication skills, appreciation of nature, problem-solving, creative thinking, and the like. But this means curriculum impacts not just on what we teach but how we teach it. We also now know a lot about human cognition, and realise that we must teach, taking account learners' current ideas and intuitions, if we wish to shift their thinking towards scientific perspectives. We also know that activities that engage learners in critical dialogue and argumentation are more likely to bring about learning than more passive tasks. Teaching does need to be informed by a good knowledge and understanding of the science, certainly, but it is equally important for teachers to know about their learners' existing patterns of thinking, and the resources students have available for interpreting teaching. Increasingly, then, assessment needs to be something built into teaching as a means of informing teaching, and providing guidance for, rather than just grading, learners. I hope that what I have talked about today has been of some interest. I know that science education in China is increasingly the focus of much research attention and innovation, and perhaps you recognise the ideas I have been discussing from the developments already taking place in China.

I would like to end by once again thanking you for inviting me to contribute to this important national conference. I hope the rest of the conference goes well and that it proves productive for all involved.
