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Vývoj fyzikálního kurikula: ne až tak rychle!

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Abstrakt

Článek zvažuje některé dobře známé problémy v oblasti učení se fyzice ve světle současných studií týkajících se způsobu, jak lidé reagují na problémy, zejména pokud jde o rozlišení „rychlého“ a „pomalého“ myšlení. Dospívá k závěru, že záleží na volbě situace, v níž učíme „rychlé“ myšlení. To vede ke kritice současných úvah o „Badatelsky orientované výuce přírodovědných předmětů“. Článek uzavírá diskuse o problémech a příležitostech, které dnes stojí před vývojem fyzikálního kurikula.

Klíčová slova: vývoj kurikula, učení se přírodním vědám, povědomost, badatelsky orientovaná výuka přírodovědných předmětů, role učitelů, obliba přírodních věd, hodnocení.

Curriculum Development in Physics: Not Quite So Fast![1]

Abstract

The paper reconsiders some well-known problems of learning physics, in the light of recent work on the way human beings respond to problems, particularly the distinction between “fast” and “slow” thinking. It concludes that much depends on the choice of situation with which to educate “fast” thinking. This leads to a critique of recent thinking about “Inquiry Based Science Education”. The paper concludes with a discussion of problems and opportunities that currently face curriculum development in physics.

Key words: curriculum development, science learning, familiarity, inquiry based science education, role of teachers, liking for science, assessment.

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[1] Editorial note: The paper is a slightly adapted version of a keynote lecture presented by professor Ogborn on July 03, 2012 at The World Conference on Physics Education 2012 in Istanbul, Turkey. The paper is published in *Scientia in Educatione* thanks to a kind permission of prof. Ogborn.

Looking back; looking forward

More than forty years ago I became involved, with Paul Black, in the development of *Nuffield Advanced Physics* (Ogborn, 1971), a course which flourished in the UK for thirty years, and introduced many significant innovations that continue to be influential. Near the end of my career I did the same again, with the course *Advancing Physics* (Ogborn, 2000). As we speak, there is a new movement sweeping Europe, under the banner of "Inquiry Based Science Education", following the Rocard Report (Rocard, 2007). To those of you involved in or affected by this development, and to those of you involved in other curriculum changes in Physics, I want to use this background of mine to do two things: first to offer some words of caution, and second, to sketch an agenda for future development.

Some words of caution

Habit, custom and familiarity

What I am about to say may seem very banal and obvious, but it is I think important and currently much neglected. It concerns the great importance of *familiarity* in making human beings feel that they understand. Roughly speaking, the rule that we all operate by much of the time is simply, "What I quickly and easily recognise is right". Easy access to the things we know is of course an essential aspect of being able to think, but unfortunately not all the familiar things we know are relevant or right. For example:

> *"Mass is the quantity of matter in a body"*
> *"Energy is what makes things happen"*

Even if you are aware that these familiar phrases make little or no sense, it is still very annoying how they immediately come back to you if you have to explain mass or energy, mainly because you don't have anything better handy.

As over the years we get used to various bits of physics, we come to think of them as much more obvious and straightforward than they are — just because they now come so easily to mind when needed. Once upon a time, Newton's laws were as mysterious to us as they still are to our students, but having got used to them we feel that we understand, even though we may understand very little more than we once did. This is both good and bad: good in that nobody should have to think everything out from first principles every time; bad in that one forgets what the first principles actually are; and bad in that sometimes one has got used to a not very good explanation which nevertheless stays feeling good.

Thinking, Fast and Slow

I have been led to this realisation even more strongly by recently reading the work of Daniel Kahneman and Amos Tversky, which won a Nobel prize for investigating economic decision making. Kahneman's book *"Thinking: Fast and Slow"* seems to me to bring into a new focus much previous research in physics education, though that was not its intention (Kahneman, 2011). He distinguishes two kinds of thinking: "Fast" and "Slow". Fast thinking, which we all use all of the time, relies on recognising things quickly, using associative memory triggered by context. It gets things right often enough to have great survival value, but — and it's a big but — it isn't always right. Worse, when it isn't right it doesn't much care: good enough is good enough. It doesn't probe more deeply: "What you see is all there is". The principle by which Fast thinking judges the correctness of an answer is simple: just by how easily it came to mind. *The easier and quicker, the more convincing.* No nonsense here about evidence and argument, or about being consistent. All these require Slow thinking, which takes effort and attention and is generally avoided by people whenever possible. Slow thinking analyses and compares, looks for logical consistency, considers alternatives, weighs up evidence. I'm sure that you recognise how you take a deep breath and brace yourself mentally when you confront a problem that really puzzles you. Empirically, your eye pupils dilate and your blood pressure rises. Slow thinking *is* hard work.

It's also the case that Fast thinking can't be turned off. It happens spontaneously without our willing it to do so. All we can do is consciously to try to turn Slow thinking on. With time and practice, we can train Fast thinking to throw up warning signals: "Think harder — you got this wrong before". With long practice and much repetition, Fast thinking takes over results from Slow, so that for example skilled mathematicians instantly recognise an integral that would previously have puzzled them.

Students' conceptions, and teachers' conceptions too

To quote Kahneman, amongst the features of Fast thinking are that it:

- works by activating associations in memory
- infers and invents causes and intentions
- neglects ambiguity and suppresses doubt
- is biased to believe and confirm
- focuses on existing evidence and ignores absent evidence

Recall these when you next read about research on students' conceptions (Duit, 2010), or about for example the seductive power of linear causal reasoning (Rozier, Viennot, 1991; Viennot, 2001). Recall them also when you think about the strategies we use as teachers to create explanations that will satisfy students, giving them the feeling (maybe the illusion) that they understand. Here perhaps is one source of Laurence Viennot's "echo-explanations" (Viennot, 2010a, b).

The fact is that we spend a lot of teaching effort in trying to get students to reach answers by Fast thinking that originally depend on Slow thinking. Ultimately, that's why rote learning can work, just by inducing familiarity so that the answer comes to mind quickly. It's why teachers invent mnemonics, which help get the answer without thinking. It is why teachers try to think up vivid analogies or metaphors, to help Fast thinking take over.

The essential job of Slow thinking is to criticise; to consider and weigh up alternatives. Quite often it can't be done entirely in your head: you may need pencil and paper, as well as calculator or computer. Notice that criticism is at the heart of scientific thought and, with experiment, is the basis of the robustness of scientific knowledge. Science in essence runs on Slow.

Finding a new point of view

How a topic is taught is generally the outcome of a familiar tradition, to which we become so accustomed that there seems to be no alternative, and the difficulties it gives rise to become invisible. These are what Laurence Viennot has called 'rituals' (Viennot, 2006); they are ways that things have customarily been done, now well-learned and habitual, to which a teacher immediately turns. Any faults that they possess have, out of familiarity, become more or less invisible. Sometimes the answer is to find a fresh way to look at the problem. I will take an extremely elementary example: the principle of Archimedes. The work of the MUSE group (MUSE, 2010) reminded me of this problem.

Archimedes' principle

Traditionally, one starts in the primary school with "floating and sinking", and children have a good time putting corks and lumps of metal into water. But then they have to be persuaded that it isn't enough to say that "heavy things sink and light things float", and to get involved with a discussion of density, which causes some trouble. Then one gets the magic form of words "the upthrust is equal to the weight of water displaced" and learns it by heart. Why a heavy metal boat can float often remains a mystery. The question why there is an upthrust often remains unanswered, even unasked: it is just what water does.

One day many years ago it occurred to me that this whole bit of teaching starts in the wrong place. Would it not be better to begin with what happens if you try to make a hole in water? For example, as in Figure 1, take a very light plastic cup and stand it on the water surface in a bowl. It hardly sinks in at all. Now push the cup down into the water a little — the water pushes back up. Push down some more — the water pushes back harder.

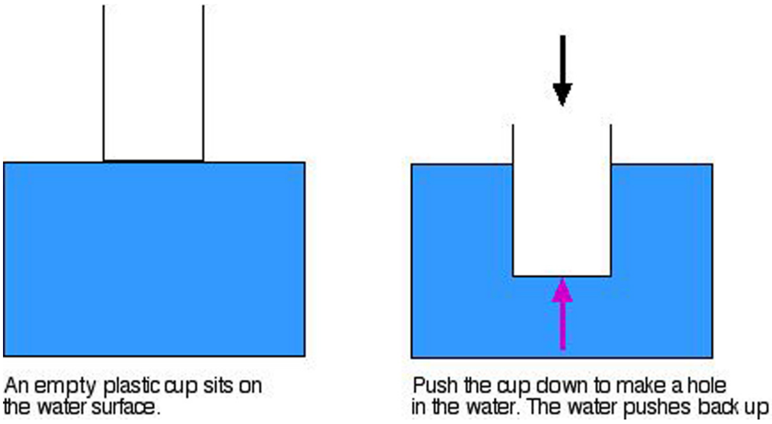
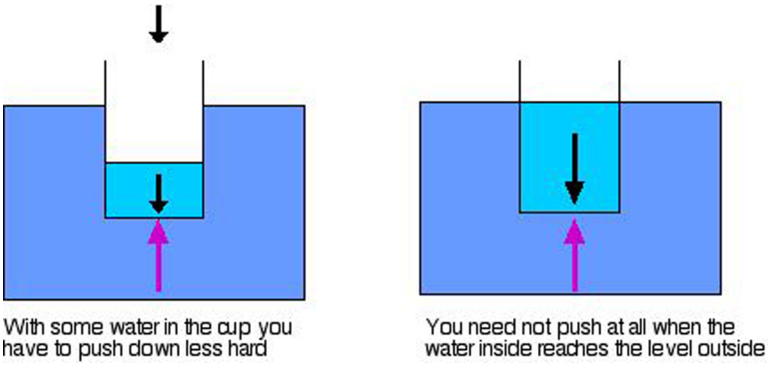


Figure 1: Make a hole in water

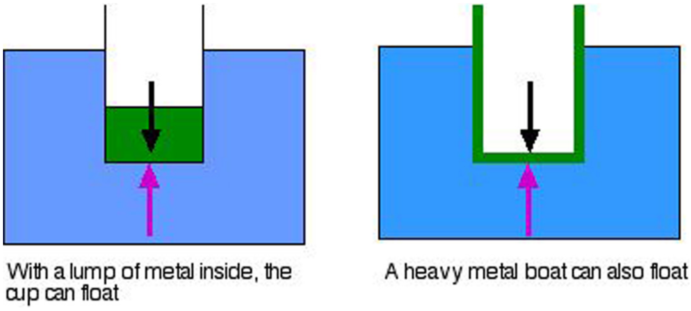
Now pour some water into the cup, as in Figure 2. When do you not need to push down any more? Just when the water inside reaches the level outside! Suddenly Archimedes' principle becomes almost obvious.

Now replace the water in the cup by a lump of metal, which is as heavy as the water, but of course smaller in volume, as in Figure 3. Then the cup will float at the same depth. What then if we made this metal into a cup of the same size? It too would float at the same level.


With some water in the cup you have to push down less hard

You need not push at all when the water inside reaches the level outside

Figure 2: Fill up a hole in water with water


With a lump of metal inside, the cup can float

A heavy metal boat can also float

Figure 3: Partly fill a hole in water with metal

Amazingly, the hard question the teacher usually has to answer, "How come that heavy metal boats float?" now becomes an easy question. The whole point is the value of starting from why things happen — in this case because of the increase of pressure with depth, caused in the end by the Earth's gravity pulling the water down so that the water below has to hold up the water above. Then Archimedes' principle can become more than a form of words learned by heart, and floating can become something explicable.

The moral for Inquiry-based learning is that the problem you pose makes a big difference! Even extremely familiar ways are not always the best, however easily they come to mind. The job of a good introduction to a phenomenon is to set up helpful associations in students' memories: in this case I want "pressure difference" to come to mind rather than (say) "density". I have to admit that such challenges to familiar ways of thinking are often very annoying, just because we all rely so much on familiarity to guide us towards the appropriate.

Inquiry-based Physics Education

Starting from these thoughts, I turn to a critical discussion of the movement for Inquiry-Based Science Education. There is of course much to commend about it, notably its insistence on the importance of students being active in learning, and having plenty of direct experience of phenomena. I do however have some important cautions to offer.

My central concern is the impossibility of replicating the scientific process of inquiry in the frame of a typical science lesson. Scientific inquiry is inherently a very Slow process, both taking a long time (years, usually) and needing the inquirer's full critical attention. Mistakes are made, wrong paths are taken. Even if there is a sudden flash of understanding, it arises from long immersion in all the details of the problem. By contrast, the classroom requires results within a short time-frame (shall we say half an hour?). It has to rely on students' intuitive responses, got by Fast thinking, which will most often be wrong or misguided, yet seem good to them, and be difficult to counter. As Manfred Euler (Euler, 2004) put it, "You understand what you see — but you see what you understand".

As a result, many such lessons become a kind of pretence. The teacher sets up a problem, knowing in advance what needs to emerge. What can emerge depends on the details of the problem-situation — compare for example floating corks versus "making holes in water". The student knows this, and often feels like saying, "If only you would tell me what to discover, I will willingly do so." In the worst case (and I have witnessed many such lessons) the practical activity becomes everything. Students try things out, perhaps write down some results, and the lesson ends — no discussion, no critical thought. The students are fairly happy, having been kept busy, and the teacher is happy, in part because no awkward questions have arisen. Of course we all know that "minds-on" matters as much as "hands-on", but I have too often seen it prove too much to achieve.

How did well-meaning teachers ever get into relying on such parodies of inquiry based learning? The big mistake is to suppose that practical activity ("hands-on") is the only thing that really matters. In fact, of course, to inquire is to *think*, and to think one must talk (and write). The task of practical activity is to provoke thought, and the teacher's main challenge is to encourage and develop productive talk and thought. This, however, makes large demands on the teacher that they find it very difficult to meet, as many researchers have found, and which requires much special training and support (Black et al, 2003). Perhaps the most difficult, and yet the most important kind of event to create in the classroom is *critical dialogue*, which recognises that inquiry proceeds by being critical of proposed ideas. It cannot help that essentially no examination questions ever require the student to offer a criticism, even the simplest. Such a focus on being critical is surely one of the greatest deficiencies that the movement for inquiry based learning needs urgently to face.

To stress the point, here are some of the key principles as stated in the booklet *Implementing and Designing Inquiry Based Science Units* from the Pollen Project (POLLEN, 2009), and my brief comments on the issues they appear to ignore.

> ## Important principles of the inquiry-based approach
> ### Direct experience is at the core of learning science.
> Students need to have direct experience with the phenomena they are studying because:
>
> - direct experience is key to conceptual understanding
> - students build their understanding of the world around them, naīve or accurate, from their experiences;
> - words alone often have little power to change these ideas.

Comment: This reads like pure naīve empiricism. Vygotski might never have existed! Instead I would say:

- direct experience is the key to making vivid and effective mental associations

- students use Fast thinking to invent plausible understandings, or to recover learned and practiced ones
- the right words, often critical ones, are needed to help students actively construct better ideas

Comparing and contrasting with “established fact”

As students investigate natural phenomena, they develop and compare their conclusions amongst themselves and construct new understanding. But unlike scientists, students are not discovering new phenomena and laws; rather what they learn in school is established scientific knowledge. Therefore they need to compare and contrast their work with the known by referring to other sources such as books, the internet or local scientists.

The use of secondary sources complements direct experience.

Students will not and cannot discover all they need to know through inquiry. The use of secondary sources in IBSE is important in the service of students' explorations, not as a substitute for them.

Comment: Your ideology is really showing! How dare you put possessing established, hard-won scientific knowledge, which is the point of the whole enterprise, in scare-quotes? It is absurd that the teacher does not appear here as a source of knowledge. The reason must be a belief that it is impossible both to be authoritative and to value students thinking for themselves. I suppose that I might say instead:

> To learn is to change one's mind; to look at things in a different way. This does not come easily or quickly, especially in science where the right point of view is often unobvious, even counter-intuitive. Where students are studying phenomena in order to understand them in the scientific way, they need to be shown how easy it is to quickly come to a wrong conclusion. They need to be persuaded to try seeing things another way, and to do this often enough for the better way to become associated with the phenomenon.

The key issue here is the source of the robustness of scientific knowledge, which entitles us to teach it. It is simple: surviving all criticism so far. If we want to teach about how scientific knowledge is made, this fact has to become central. We have to *require* students to criticise ideas, not merely tolerate it. And they have to expect their ideas to be questioned too. The truth is that a life in science is not very comfortable, because one's colleagues systematically doubt everything one says.

An epistemological problem

There is a real danger that Inquiry-based learning presents scientific knowledge as “knowledge in pieces”. Planning a sequence to “establish a given concept” doesn't really make sense, because ideas in science are strongly interdependent. That is, any new idea must not only be consistent with the evidence, but must also cohere with everything else we know. This makes it crucial to ask always about possible connections between ideas and explanations, so that science can be seen to be a coherent whole.

Agenda for the future

What then are some of the important things for us to try to do in developing the physics curriculum in the future?

Resources as well as inquiries

Despite the criticisms so far, I do believe that there is an important role for students to actively study phenomena in the laboratory, in a spirit of inquiry. But I also believe that they need to be set up in advance with the necessary intellectual resources to do so. My broad-brush picture is thus one of episodes, first of learning some background ideas (probably with lots of demonstrations too), leading to a question and to an inquiry to try to go deeper into that question (notice that I didn't say "resolve the question"). The curriculum design problem is then to identify fruitful issues for inquiry, together with useful resources for thinking and experimenting that need to be taught first, and then to articulate these effectively together. Paul Black discusses an example of this idea, worked out in detail, in his account with Myron Atkin of their experience of science education reform (Atkin, Black, 2003). It is this, too, which is a main focus of the work of the MUSE group.

Real investigation

I am also utterly convinced that Physics education must include an element of real, genuine investigation for students to experience. This cannot however, at the same time, be used to develop new scientific concepts (Millar, 2012). The problems investigated have to be much more modest, within the student's current grasp.

What investigation needs above all is time — time to try things out, to make mistakes, to think and think again. It also needs ownership and responsibility, so the individual student must have choice about what to investigate and how to go about it. It is worth pointing out that perhaps the most successful and lasting innovation in Physics education over the past fifty years has been the introduction of undergraduate research projects. Carefully thought out, the idea has proved workable and long-lasting in school Physics too, but only if given enough time – 10 hours is not too much for one serious investigation. Experience of doing it in *Nuffield Advanced Physics* and in *Advancing Physics* for what is now over forty years points to several key factors:

- the student must choose what to investigate
- investigations have to be kept very simple, but be given enough time
- assessment must include credit for having detected and recovered from mistakes.

Changing the curriculum

Reasons why it may be desirable to change the teaching of a topic in physics, or to introduce a new one include:

- The need to update the content of the physics curriculum
- The need to improve the way established topics are taught
- The need to make physics more attractive to students

Over time, perceived needs change. In the 1960s the need to update the physics curriculum was paramount; today the major concern is that students, especially girls, find physics unappealing. As a result the emphasis has shifted from *what* to teach, to *how* to teach it. Furthermore, Physics Education Research has, over the last thirty years or so, focused mainly on questions about *how*; about how students do or don't come to understand important ideas in Physics, and what can be done about it.

Let me encourage you not to forget questions about *what* to teach, both to update the content of the curriculum and to improve the way traditional topics are presented. This often means thinking deeply about the fundamental basis of ideas, and finding good ways to represent these to students.

In wanting Physics to be attractive, we should remember the exciting new topics that find their way into popular science on television and in books. In particular, I think that you should be considering such things as:

- Digital communication, especially imaging in science and technology, from satellite navigation systems to astronomy and medicine
- The essential role now played by computational modelling both in technical design and in theorising
- Current cosmological arguments, including dark matter and dark energy
- Particle physics; why we need huge accelerators and what they can discover
- Developments in the creation of new materials, and their uses.

It is however a very awkward fact about Physics that several of its most crucial modern (and not so modern) insights seem to remain inaccessible to the school curriculum. Some of the best times of my life have been spent creating ways to teach the essential ideas of, for example, thermodynamics and quantum physics. Many others have tackled the teaching of relativity. On the agenda for the future we might place:

- Symmetry and its relationship to conservation
- The connection between spin and statistics
- The essential role of quantum phase in accounting for the existence of interactions (Ogborn, Taylor, 2005).

There have been brave attempts, for example Richard Feynman's classic book *"QED: the strange theory of light and matter"* (Feynman, 1985), but few have been followed up.

Making Physics attractive

Many, many curriculum development projects (from Harvard Project Physics onwards) have set out to make Physics more appealing to young people, most recently with special emphasis on young women. Despite huge efforts and high hopes, the results have generally been disappointing, sometimes even showing a small fall over time rather than an increase. (The excuse Harvard Project Physics gave was "too much of a good thing".) I see recently similar results coming out of the Pollen project (Jarvis et al, 2009; Lindahl, 2009). I think that it may even be true to say that no curriculum development project has ever achieved a major shift in the overall average of students' liking for the subject.

This sad fact is actually not too surprising. Firstly, young people's attitudes form quite early in life, and because they form part of their self-identity are hard to shift. Secondly, young people often actually resist attempts by older ones to please them: they prefer to please themselves, and are suspicious of well-meaning attempts to second-guess what they would like.

So what can be done? I think that one answer is honesty and pride in the value to us of Physics. An important part of this is the intellectual satisfaction of having seen how, despite difficulties, it provides models and theories of remarkable power, consistency, generality and parsimony. Overcoming the difficulties, with help when needed, is a real part of the attraction. I quite accept that this is not a populist recipe, though inviting students to be really critical of what they are told might be more welcome than one expects. Indeed, one reform I would dearly like to see is classroom exercises and examination questions giving marks for criticising flawed arguments or procedures.

The other answer is to recognise the importance of variety. There are many ways in which Physics can appeal, not only through its power and beauty, but also through its practical understanding of how things work. It is I believe essential to build in variety as a fundamental criterion for choosing the content and activities for the curriculum, so as to appeal to as many different kinds of people as possible.

Concluding thoughts

Slogans

Curriculum development shares with politics the need for simple vivid slogans encapsulating its aims, just to catch sympathetic attention and perhaps commitment.

- "Hear and forget; see and remember; do and understand"
- "Science for All"
- "Discovery Learning"
- "Ask Nature"
- "La Main à la Pâte"

Be very wary of these slogans (remember how good Mao Zedong was at creating them.) Although essential and unavoidable to focus enthusiasm and to help people grasp the point of the activity, they rarely speak plainly. So be very suspicious of any development project that seems to believe its own propaganda. The reason is that in something as complex as Physics Education, there simply are no easy 'one-shot' solutions; there are no 'magic bullets'. Look instead to see whether there is careful attention to practical detail, sympathetic allowance for differences of circumstance and competence; above all, whether there is respect for and serious involvement of the actual teachers who have to do the job.

Pathologies

We live in a time of widespread belief in management, technique, efficiency and targets. In the UK at present, schools and teachers increasingly live or die by whether they reach targets, generally of student performance in tests. This raises the stakes very high, and it is no surprise that teachers try to subvert the system. If they can train students to pass, by whatever means, they will.

Let me put this in an even more challenging way. The job of a teacher often becomes getting students able to counterfeit understanding. The examiners set clever questions they think will really test understanding; the teacher tries to anticipate them and train the students to know the answer without thinking.

Getting it all right

Finally, I want to draw out some general messages about changing the physics curriculum, if such changes are to have any chance at all of working in the real educational world.

First, it is essential to keep hold of the big picture, and communicate it to teachers. Teachers will never teach exactly as suggested, and need to be able to remember why a topic is there and what ends it serves, to judge the way they will go about it.

Second, the devil is very much in the detail. To be effective, the teaching suggestions must really work, the experiments suggested must be practicable, the questions provided must address the right problems and be able to be tackled by the students. And so on. Teaching is a very practical day-to-day business, in which a small practical hiccup can ruin a grand master plan.

Third, offer lots of teacher training. It takes time and confidence to do anything new. Indeed, as soon as you step outside well-practiced teaching routines you tend to feel helpless, not able to answer a student's questions, not able to think of what to say next, etc. Taking on board a big innovation is, for a teacher, like going back to the first days in the classroom. No wonder that very often old routines are wheeled out and substituted for the new.

Fourth, and very importantly, worry about and work right from the beginning to develop the assessments to be used during and after the course. They will determine what teachers and students understand you as 'really wanting'. In the end, the forms of assessment that you use will be decisive, and you need to be in control of them. Don't forget to provide a lot of formative assessments for teachers to use while teaching, to tell students and teachers how well they are doing and where they need to improve. There's lots of evidence that good formative assessment really helps learning (Black et al, 2003). And do remember that generating new kinds of questions is not easy: it takes time, imagination, trial and error and hard work.

Lastly, arrange continual support for teachers, for example an email network on which teachers exchange opinions, ask for help with a confusion, tell each other where to get the latest bit of apparatus or where to find the newest internet resource, and so on. The discussions include gripes and moans, questions about fundamental physics, queries about dates for submitting coursework — in short everything, large or small, deep or trivial, that make up a teacher's everyday concerns.

Serious curriculum change happens gradually, and so does learning. Thus, in final conclusion, a piece of advice from Paul Black and Myron Atkin (2003). It is very simple:

Make haste slowly!

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