Learning doctors – diagnostic skills for science teaching

The metaphor: The 'Learning Doctor'

Science teaching does not always bring about intended learning - for all sorts of reasons. This is true, even with attentive, motivated learners who were present and on task.

We might say there are 'bugs' in the teaching-learning-system.

Signs and symptoms

Students may, or may not, demonstrate the symptoms of the 'bug'. They may look confused, and tell you that they do not understand, or that they can not do the work.

The absence of any symptoms (yet) does not mean there is no bug. Careful examination may reveal the signs - the things students say, write, draw and do in science which suggest they have not understood the science as you intended.

Diagnosis

The science doctor uses the symptoms and signs revealed during her examination to try to identify the nature of the learning bug - to diagnose what has gone wrong during the learning-teaching system.

But before we consider treatment…

Prevention is better than cure

Many potential science learning-bugs are avoided by thorough planning:

- By careful analysis of the concepts to be taught to identify pre-requisite knowledge, hierarchical structure, important links
- By careful checking of student prior knowledge
- By careful logical development of the topic

Conceptual matching

In other words, planning allows 'conceptual matching':

> *planning enables the science teacher to make informed decisions about the current state of the learner's knowledge, and so plan how to go about constructing new knowledge on the existing foundations*

The teacher's presentation is designed to match - to fit against - the existing conceptual knowledge and understanding of the learners.

However, back in the real world of real classrooms, individual learners' conceptual frameworks

- are all different, and may
  - be multifaceted,
  - have unexpected ranges of application, and
  - idiosyncratic aspects

So thorough planning will never *completely* avoid mismatches between the expected and actual existing knowledge in the class.

Pragmatism

The effective science teacher therefore has a *two-phase* approach:

1. being as thorough as possible in planning - to match teaching to students as well as possible – but
2. being aware, and being sensitive to, the learning bugs that inevitably occur

Diagnosing learning bugs

Diagnosis of learning bugs allows the science teacher:

- to modify planning for future teaching
- to respond to identified bugs, and work with students - to cure the bugs

Failures are opportunities
Often students' incorrect/incomplete/missing answers and comments indicate that teaching has not been effective, and so provide a new opportunity to reinforce intended learning through remedial work.

The typology of learning impediments: A heuristic tool

The notion of the 'mismatch' between the assumed existing conceptual structure (assumed by the teacher when planning teaching), and the actual conceptual structure used by the student, suggests a typology of possible blocks or impediments to effective learning. Such a typology of learning blocks may be a helpful diagnostic tool.

Two types of potential block
A major distinction is between situations when

- the learner is unable to make sense of the teaching in terms of existing conceptual frameworks, and when
- the learner interprets the teaching *differently* to how the teacher intended.

NULL and SUBSTANTIVE blocks

- a null learning impediment is when the learner does not relate teaching to any existing knowledge;
- a substantive learning impediment is when teaching is related to existing knowledge and understanding, but in such a way as to *distort* the *intended* meaning

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NULL LEARNING BLOCKS

In a NULL learning block, *the teacher assumes* prior learning that will act as foundations for new learning, but the student *does not make that connection*. There are two possible reasons for this.

Null learning impediments may be:

- **deficiency** learning impediments - where the learner's conceptual structure does not include the assumed prior learning, or
- **fragmentation** learning impediments - where the assumed prior knowledge is present, but is *not activated* ('brought to mind') by the learner

Making good the deficiency

Deficiency learning impediments: If prerequisite knowledge is absent, the teacher needs to make good the deficiency - so that sound foundations are available for constructing new knowledge. This may include providing experience of some phenomenon.

Making the connection

Fragmentation learning impediments: If appropriate prior learning is present, but is not brought to mind, then the teacher has to help activate this knowledge in the context of new learning, i.e.

- make the connections more explicit
- use suitable examples, analogies etc.

(One description that could be applied to much science teaching is 'making the unfamiliar familiar'.)

SUBSTANTIVE LEARNING BLOCKS

SUBSTANTIVE LEARNING IMPEDIMENTS occur when the student *does activate* existing knowledge to make sense of teaching - but does not *interpret t*he teaching in terms of the expected prior learning, in the way intended.

It may be useful - in terms of responding to learning bugs - to identify a range of possible sources of misinterpretations. (In reality, many cases may not be so simple or clear-cut.)

A SUBSTANTIVE LEARNING IMPEDIMENT will occur either if:

- the students' existing knowledge \ understanding does not match the curriculum version, or if
- the student tries to apply inappropriate existing knowledge in the new context

Grounded learning blocks

A **grounded** learning impediment occurs when aspects of existing knowledge \ understanding do not provide sound foundations for new learning. Inappropriate beliefs may derive from:

- 'intuitive' learning: the way the world seems to be
- social sources: 'life-world' knowledge, folk beliefs
- poor pedagogy: flawed curriculum models, or ineffective previous teaching

Associative learning blocks

An **associative** learning impediment occurs when the student understands teaching in terms of knowledge that is inherently sound, but makes *inappropriate connections*, e.g.

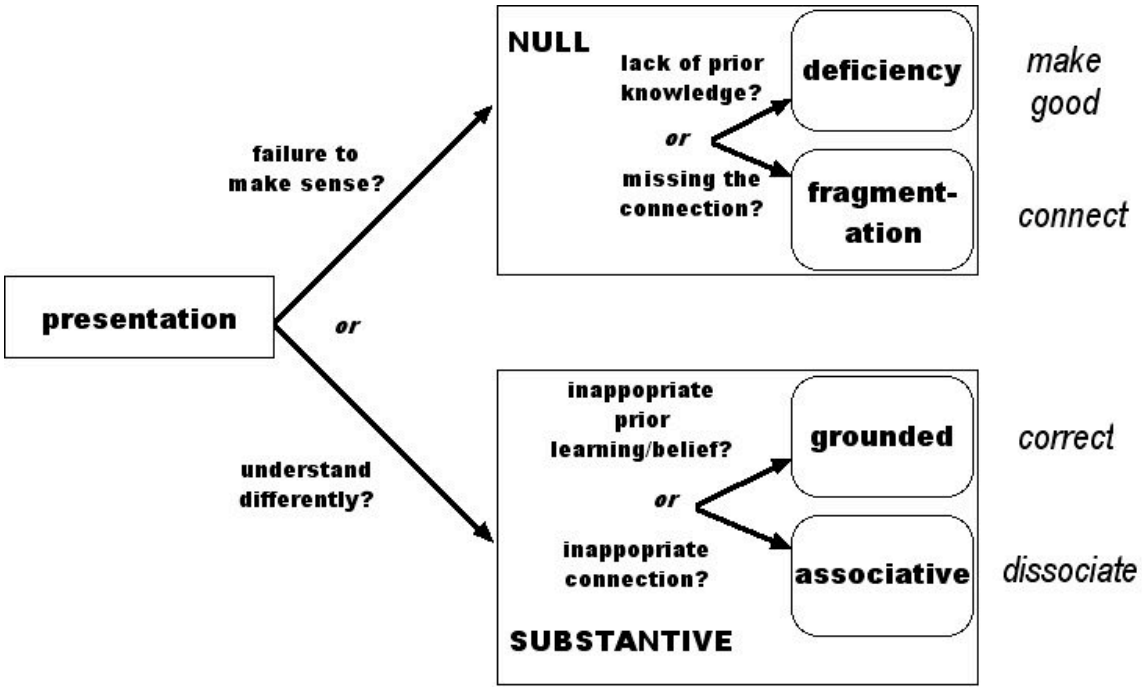
- by misinterpreting linguistic cues
- by drawing inappropriate analogies
- by failing to appreciate the nature of scientific models

Learning blocks typology:

NULL LEARNING IMPEDIMENTS
- **Deficiency** learning impediments
- **Fragmentation** learning impediments

SUBSTANTIVE LEARNING IMPEDIMENTS
- **Grounded** learning impediments
  - 'intuitive'
  - social / 'life-world', folk beliefs
  - previous teaching
- **Associative** learning impediment
  - linguistic cues
  - inappropriate analogies
  - nature of models

Diagnosis of learning bugs: flow chart



The value of the typology as a model is that knowing what has gone wrong, gives an idea of what the teacher's response should be.

An alternative way of representing this information is given as a 'key' on the following page.

This is only a model. Clearly this approach is neither full-proof, nor comprehensive: but if does offer a useful heuristic for making sense of, and thinking about how to respond to, learning bugs.

The chart above, and the 'key' questions that follow, may be useful when trying out and experimenting with the approach. However, the intention is not so much that teachers should use this model in a formal way, but rather that they

- develop sensitivity to learning bugs
- develop a mind set that learners' mistakes have causes, that can sometimes (often?) be diagnosed
- understand that the most appropriate response to learning bugs varies, depending on the type of bug.

Diagnosis of learning bugs: key questions

1. Does the 'presentation' (e.g. the comments of the learner) suggest that they have not made sense of what they have been taught in terms of prior learning (2), or that they have understood it differently? (3)
2. *The student has not made the expected connection with pre-requisite learning*. Is this because they have not learnt material that is needed as the basis for the new learning? (4) Or: is it that they have not 'made the connection'? (5)
3. *The student has misunderstood what they have been taught*. Is this because they hold some alternative beliefs that do not match scientific knowledge? (6) Or: have they made some inappropriate connection with existing knowledge that is not relevant here? (7)
4. *The student lacks essential prior learning*. Before they can understand the new material in the way required, there needs to be some remedial work to fill-in the missing knowledge.
5. *The student has not brought to mind the prior learning that the teacher intended to act as the basis for understanding new work*. Here the teacher needs to make the connections explicit – to show the learner how the prior learning is relevant to the new material.
6. *The learner holds some alternative conception / belief / framework which is inconsistent with the science in the curriculum*. This is an area where this is a great of literature exploring both students' conceptions/beliefs and discussing whether it is best to:
    a. challenge them and try and show them inconsistent/false etc., or
    b. try to help the learner develop them into something more like the desired knowledge or
    c. ignore them, and try and provide an alternative (scientific) version that will be more coherent and useful.
7. *The learner has seen a connection with prior learning that is not appropriate*. This is unfortunate, as generally teachers wish to encourage learners to 'see the connections' and much progress in science depends upon creative insights for how apparently disparate topics may be connected or other productive analogies. Here the teacher needs to explain that the connection is not appropriate, and why/how it falls short where this is possible.

Some examples of learning bugs:

A learner believes that an object will naturally come to a stop without any force acting (where school physics claims that an object will continue to move in a straight line for ever, unless a force acts!) This very common belief would seem to be based on childhood experience that objects that are pushed, kicked etc, only move so far before coming to a stop. Physicists explain this in terms of air resistance, gravity and friction, but young children do not recognise such effects as forces and seem to develop the 'impetus'-like notion.
(1→3→6: grounded learning impediment – intuitive belief).

A learner believes that the reaction between an acid and an alkali must produce a neutral product (where chemistry tells us this depends on the strength of the acid and alkali). This may well be due to connecting the term *neutrali*sation with *neutrali*ty. Any acid-base reaction is described as *neutral*isation, although the product may be *neutral* (potassium chloride) or not (sodium ethanoate).
(1→3→7: associative learning impediment – linguistic cue)

A learner draws a picture of the particles in a solid, and draws a line around the outside representing the surface of the material containing the particles. At one level, this can be seen as 'fragmentation' problem in that the particles are not associated with the surface. However, it may be more productive to see this as lack of suitable knowledge or experience to make sense of the molecular world. After all, the surface is continuous even if the material is made up of discrete particles. At the macroscopic level surfaces are about the edges of stuff – whereas the molecular level the surface is about the net electric field. Some kind of experience and/or model is needed to get the learner to see the surface as a kind of 'force field', and the particles as a battery.
(1→2→4: deficiency learning impediment)

A learner believes that the material making up a tree comes from the ground (where science teaches that the carbon is sources from the air through photosynthesis). There may well be an intuitive aspect here – in terms of the

impact of seeing the large roots of trees. However, this may often largely be due to 'life-world' (everyday) talk about plant 'food', and 'feeding' plants. (1→3→6: grounded learning impediment – life-world)

A learner assumes that the atomic nucleus gives out a force which is shared equally between the orbiting electrons. The chemistry teacher was aware that this student had studied Coulombic principles in a physics lesson and assumed (reasonably?) that the learner would realise these are applicable here. However the student did automatically see the 'special' atomic context as one where prior learning about forces between charges should apply (1→2→5: fragmentation learning impediment)

References:

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Taber, K. S. (2004) Learning quanta: barriers to stimulating transitions in student understanding of orbital ideas, *Science Education*, 89 (1), pp.94-116.

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Learning blocks typology:

NULL LEARNING IMPEDIMENTS

The intended learning may not take place because the student is unable to make sense of the teaching in terms of existing ideas

Deficiency learning impediments

This may be because the student has never acquired the necessary pre-requisite knowledge…

Fragmentation learning impediments

…or the student may simply not recognise how their existing ideas are relevant

SUBSTANTIVE LEARNING IMPEDIMENTS

Learning may occur which does not match the intended learning because the student interprets teaching in terms of existing ideas in a different way to intended

Grounded learning impediments

This may be because existing understanding is inconsistent with accepted scientific thinking. Such 'alternative conceptions' may derive from various sources:

'intuitive'

…the students' own intuitive interpretation of the way the world seems to be…

'life-world' - folk beliefs

…or common scientifically dubious ideas acquired from friends, family, the media etc.,…

'pedagogic' – from previous teaching

…or pedagogic impediments due to limitations of previous teaching (over-simplification, poor analogies, etc)

Associative learning impediment

This may be because the student makes an unintended link with prior learning:

'linguistic'

… taking a cue from a word's 'everyday' usage, or the similarity of a word with the label for an existing concept…

'creative' - inappropriate analogies

…or spotting (creating) an unhelpful analogy between the material being taught and some existing knowledge…

'epistemological' – over-interpreting models

…or lacking the epistemological sophistication to appreciate the limitations of models, analogies and metaphors used in science teaching, and so interpreting teaching in a too literal and absolute sense

Some hypothetical examples of substantive learning impediments – is it possible to characterise them using the typology?

Billy cannot suggest a structure of the molecule of PF_5. He has previously been taught that atoms can only accommodate 8 electrons in their outer shell.

Bobbie says she knows that astronauts on the space shuttle fly outside the earth's gravitational field as her friends have seen television programmes of the astronauts floating around the cabin.

Hardeep thinks that a solution of the salt potassium ethanoate will have pH of 7 as it is the product of a reaction that his teacher called 'neutralisation'.

Julie cannot understand the difference between a chemical and physical change. She does not believe that hard cold ice, and clear flowing water can in any sense be the same sort of stuff.

Simone has learnt that photosynthesis can be represented by a simple chemical equation. She does not understand how photosynthesis can be a multi-stage process.

Tomas says that magnetism is due to two types of magnetic particles, called North and South poles, that are found in all matter, but are in balance in materials that are not magnetic.

Examples of possible origins of learning impediments

example	commentary
Billy cannot suggest a structure of the molecule of PF_5. He has previously been taught that atoms can only accommodate 8 electrons in their outer shell.	Here previous teaching has included scientifically incorrect information. Prior learning (substantive) leads to a pedagogic learning impediment.
Parminder does not understand that if ultraviolet radiation has a higher frequency than infrared, then it will be potentially more damaging.	Here assumed prior learning about the relationship between energy and frequency (E=hf) may be absent: a deficiency in existing knowledge acts as an impediment to learning.
Bobbie says she knows that astronauts on the space shuttle fly outside the earth's gravitational field as her friends have seen television programmes of the astronauts floating around the cabin.	Here 'general knowledge' derives from the sharing of folk beliefs. Scientifically dubious knowledge from everyday conversation in the 'life-world' provides a substantive learning impediment.
Hardeep thinks that a solution of the salt potassium ethanoate will have pH of 7 as it is the product of a reaction that his teacher called 'neutralisation'.	Here a quite reasonable, but scientifically inappropriate association is drawn due to a linguistic cue: neutralisation implies neutral.
Julie cannot understand the difference between a chemical and physical change. She does not believe that hard cold ice, and clear flowing water can in any sense be the same sort of stuff.	Here a common-sense interpretation of everyday phenomena acts as an (intuitive) substantive learning impediment. Differences in material properties are much more cogent than identify of chemical substance.
Simone has learnt that photosynthesis can be represented by a simple chemical equation. She does not understand how photosynthesis can be a multi-stage process.	Here a simplification used to model a process is over-interpreted and the learner associates a single equation with a simple one-stage process, not appreciating how a complex phenomenon can be modelled at various levels of complexity.
Amy can explain why enzyme catalysed reactions stop being effective above a certain temperature, but not why rate of reaction increases with temperature below that point.	Here there is a failure to explain rates of reaction in this complex biological case with the collision theory model used to explain kinetics in chemistry topics: knowledge is compartmentalised – a fragmentation learning impediment.
Tomas says that magnetism is due to two types of magnetic particles, called North and South poles, that are found in all matter, but are in balance in materials that are not magnetic.	Here an association is drawn by analogy between electrical and magnetic forces, and features of the familiar electrical case are incorrectly assumed to have direct parallels in the magnetic case. (But award marks for thinking!)