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The Nature of Student Conceptions in Science

Introduction

Prior knowledge - what learners already know and understand - is a major determinant of what students will learn from their science classes (Taber, 2015). A great deal of research suggests that very commonly students may hold ideas about science topics which are different to, and indeed often inconsistent with, canonical scientific principles and theories (Duit, 2009). Studies have described learners' own ideas about science topics in various ways such as misconceptions, intuitive theories and alternative conceptual frameworks, although there are not widely agreed meanings for these different terms. Research also suggests that the ideas elicited from students vary on a number of dimensions that influence how significant student thinking is for learning canonical scientific ideas (Taber, 2009). The chapter explains how student conceptions in science can vary in terms of degrees of acceptance, connectedness, multiplicity and explicitness. The nature of each of these dimensions is described in the chapter drawing upon examples from research into student thinking about science topics, and the significance of each dimension for student learning is explored.

The significance of prior learning

The perspective informing this chapter is sometimes called personal constructivism (or psychological or pedagogic constructivism). This is a perspective on the nature of learning and human knowledge that suggests that knowledge is not the kind of thing that can be simply copied between minds (for example, from the teacher to the student) but rather has to be constructed anew by each knower. This perspective is informed by research on human cognition which suggests that the human mind acts to make sense of the world by recognising patterns in experience as a basis of constructing models that allow a person to anticipate the future. The young child knows (i.e. has developed an expectation based on patterns of past experience) that letting go of the toy will lead to it dropping to the floor, that kicking the ball harder will lead to it travelling further across the garden, and that crying usually leads to the appearance of mother.

This process of developing models in the form of expectations is quite conservative in the sense that once patterns are recognised and expectations established, they tend to be automatically used to filter and interpret new experiences. Letting go of a helium filled balloon that does not sink to the floor may be surprising, but does not lead to immediately expecting that other objects released into space will also float away. The human brain has evolved to be an apparatus that makes sense of the world in terms of the existing set of models. It can also augment and adapt those models in the light of new experience: but, once established, existing patterns of thought tend to dominate.

Much school level learning is language-based of course, but there are strong reasons to consider that the expectations of the world built up in early childhood are important foundations for all later learning (Vygotsky, 1934/1986), including the learning of abstract academic concepts presented in formal language (Lakoff & Johnson, 1980).

Learning is interpretive, incremental and iterative

In effect, human learning tends to be interpretive, incremental and iterative (Taber, 2013b). Learning is interpretive as sensory data (including that deriving from teaching) is processed through the brain's sense-making apparatus to produce perceptions of the world. Our current models of how cognition works suggest that learning is incremental because a key part of our cognitive apparatus, working memory, only attends to a very small amount of new input at any time. This is indeed an *inbuilt bias* as previously learnt material can be 'chunked' into extensive complexes that can be processed in working memory, whilst only a few discrete items of novel 'input' can be considered at a time. Thus when teaching, we have to consider the material to be taught from the learner's perspective and organise it into what will be manageable 'learning quanta' at the learner's resolution. The nature of such learning quanta will depend on the extent and level of integration of the existing knowledge and understanding that a particular learner is able to draw upon to make sense of teaching.

Learning is iterative because it is interpretive - once a student has developed a particular understanding then they will interpret new information according to this way of thinking, and tend to learn it in a way that reinforces the existing interpretation. We certainly can, and do, develop new ways of thinking, but the brain has evolved primarily to seek to fit new information within existing ways of understanding, and that is what usually happens.

Given all this, a major determinant of learning is what is already believed or understood. Making sense of teaching requires the learner to process what they are hearing and seeing through their existing interpretive resources - something that is usually largely automatic and so the learner is not even aware it is occurring - and the particular meanings that they take from teaching depend upon the particular resources brought to bear.

What can go wrong in teaching?

If we understand that learning is an interpretive, incremental, and iterative process then this means that science teaching is a process of guiding learners to construct understandings of the world that match the scientific models as well as possible -given that they will always be relying on their existing knowledge and understanding to interpret the teacher's presentation. In designing lessons, teachers need to plan their presentation of material so that it makes good sense to students and will be interpreted as intended. To do that well, requires a knowledge of the learners' current state of knowledge and understanding (Driver & Oldham, 1986). If there is a mismatch between how the teaching is intended to be understood, and how it is actually made sense of, then the desired learning will not occur.

There are different kinds of basic mismatches that may occur, leading to different kinds of impediments to intended learning (Taber, 2005). Sometimes the teacher assumes prior knowledge that the students do not have. It is also possible that when students do have the expected and needed prerequisite knowledge they do not bring it to mind during teaching. So the teacher may assume that everyone in the class appreciates the relevant prior learning, but some students may not see its relevance and so are not interpreting teaching in the way intended. Teachers should always be explicit about how new teaching is intended to build upon prior learning. Sometimes it may be possible to ensure this by using a preliminary activity which both highlights essential pre-requisite knowledge and helps students re-organise it into the most useful form to support building the intended new learning from it - what has been called a scaffolding PlaNK - a 'platform for new knowledge' (Taber, 2003).

It is also possible that learners do relate teaching to existing knowledge and understanding, and so do interpret teaching in a way that makes sense to them, but *not* in the way intended. If they do not have, or do not recognise the relevance of, the prior learning they are expected to bring to mind, then they may well instead make links with other ideas they do have available. The links may be irrelevant or even inappropriate from the teacher's perspective, but the student will not realise that. Despite this being unfortunate in the context of that particular lesson, this shows that students are being active learners, and creatively seeking links between different features of their learning. This is something to be encouraged, as science itself relies on suggesting such creative possibilities (Taber, 2011). The concepts that students learn in science - magnetic fields, photosynthesis, oxidation - were once brave new ideas deriving from someone's creative imagination. Most such ideas do not survive extensive testing, so science relies on lots of imaginative suggestions to be scrutinised and selected from. Having wrong-but-creative ideas is therefore a positive trait in a science student, so the teacher should be encouraging this tendency even though many of the outcomes are unhelpful in the context of the particular lesson (Kind & Kind, 2007). Students will have such ideas whether they share them or not, and when the teacher dismisses them in a critical way this will only encourage learners to keep such ideas to themselves. That makes the teacher's job more difficult.

The other possibility is that the learner does relate teaching to their previous knowledge and understanding about the appropriate topics or concepts - but that existing understanding is not canonical. That is they may already hold alternative conceptions of the topic area at odds with the accepted scientific accounts. Research has revealed that learners at all levels (including some teachers) commonly hold notions that are inconsistent with the science that is taught in the curriculum.

Learners' ideas in science

Research shows that even when a class meets a science topic for the first time in the curriculum, teachers cannot assume that students do not know anything about the topic, as quite often learners have developed their own ways of thinking about science topics before being formally taught about them. These ways of thinking are sometimes consistent with the scientific accounts met in school and college science - but certainly not always. Moreover, research also shows that teaching does not necessarily 'correct' students' ideas that do not fit with science. Students' alternative ideas will sometimes be changed by teaching, but not always. Moreover, teaching sometimes leads to the modification of existing ideas in unintended ways, and even the development of *new* 'wrong' ways of thinking. (There are some examples in the Chapter on '*Beliefs and Science Education*'.) So again we see that science teaching has to be seen as responding to, and channelling, students' existing thinking, not just passing on scientific knowledge.

There is a vast research base exploring students' ideas in science, and a range of terms have been used to label and categorise these ideas (Duit, 2009). Anyone reading research in this area (and much of it is fascinating, as well as being useful to inform teaching) will find references to a whole range of descriptors: alternative conceptions, misconceptions, intuitive theories, alternative frameworks (or alternative conceptual frameworks), minitheories, p-prims, knowledge facets, intuitive knowledge elements, preconceptions, etc. Although some of these different terms are intended to relate to genuine distinctions, sadly there is little consistency in how such terms are used across the literature. Here I will refer to learners' conceptions, many of which (those that are inconsistent with canonical science) are considered alternative conceptions.

Learners' Conceptions

A conception is a way of making sense of something - a way of conceptualising. In order to write about conceptions we need to formulate them in verbal terms, but we should bear in mind that student thinking about science is not all verbal. Indeed scientists' ways of thinking about science is not limited to verbal language: Einstein is just one example of a major scientific thinker who visualised a lot of his scientific ideas, before reformulating those ideas in equations and words (Miller, 1986).

Examples of students' conceptions

As the research literature reports vast numbers of conceptions related to scientific topics, it is only possible here to discuss a few examples and invite readers to consider the possible implications of such ideas for teaching students these topics. Perhaps the reader will imagine they are teaching a class the relevant topics and ask themselves how they would adapt their teaching if students in the class held the following alternative conceptions:

- a ball that has been thrown into the air is subject to an upwards force during the period it is moving upwards;
- no force is required to make an object move in a circle as long as the speed of the object does not change;
- a woman cannot get pregnant the first time she has sexual intercourse;
- the product of a neutralisation reaction is always neutral;
- current diminishes around a series circuit;
- insects are not animals;
- mushrooms are plants;
- compounds such as SF_6, PCl_5 and IF_7 cannot exist as atoms can only have eight electrons in their outer shells;
- a hydrogen bond is a covalent bond to a hydrogen atom;
- intelligence is fixed at birth;
- cave men used to hunt dinosaurs
- the Earth is nearest the Sun in summer...

It is very likely that readers who are experienced science teachers will have come across many other examples of ideas students have which are at odds with the science taught in schools and colleges.

Responding to student's conceptions

As suggested above, when students who hold alternative conceptions come to science lessons and are taught science that is inconsistent with their ideas, a number of things can happen (Gilbert, Osborne, & Fensham, 1982). These include:

- sometimes students shift their thinking to take on the scientific account in place of their previous ideas;
- sometimes students effectively ignore and soon forget the teaching and maintain their previous ways of thinking;
- sometimes students learn the new scientific ideas, but as something additional to their existing ways of thinking (even if these seem inconsistent with each other);

- sometimes students modify their existing thinking to some extent in the light of the teaching - to a new conception intermediate between what they thought before and what the teacher is intending them to learn;
- sometimes students modify their existing thinking to some extent in the light of the teaching - to a new conception that is a hybrid containing elements of previous and canonical ideas, but not quite matching either.

This list is simplistic in an important sense as it seems to imply that teaching and learning are nicely compartmentalised as occurring in a lesson and so lead to particular outcomes. In practice, the learning process continues long after the lesson and the students' thinking may only slowly shift (as there are ongoing brain processes which revisit memories of experiences and act over time to modify the way we think about things). Teaching is seldom organised into totally discrete lessons - usually teachers teach sequences of lessons on a topic, revising and developing points over several lessons. A student's understanding of, say plant nutrition, before the lesson where photosynthesis is introduced, immediately after that lesson, at the end of the full sequence of lessons in the topic, and a month beyond that, may all be different.

Given this complex situation, different recommendations have been made to teachers about how to best deal with learners' alternative conceptions. In particular, three common suggestions are to (a) ignore them; (b) challenge them; and (c) build on them. Such a diverse range of options seems unhelpful to the teacher - but actually each of these options may be sensible sometimes (as will be explained below).

It is sometimes suggested that teachers should just ignore students' ideas because often they are not significant for learning, and then paying attention to them in the classroom will simply reinforce them and confuse students about which ideas are being validated by the science lesson. However, there are also strong suggestions in the literature that students' alternative conceptions *can be* tenacious, and come to dominate their thinking about a topic, unless they are challenged. Challenging usually involves demonstrating or arguing why these ideas do not fit observations and other evidence, and are less useful than the scientific models.

An alternative argument, also often made in the literature, is that as students' existing conceptions are the (only) resources they have available for constructing new learning, they should be worked with rather than challenged. This argument suggests that what appear to be firm conceptions are often best understood as the result of the learner putting together fairly isolated knowledge facets or ‘knowledge in pieces’ which can be in effect dismantled and rebuilt to form scientific conceptions. Of course, the arguments made in research literature are being summarised and simplified here, and deserve more careful study.

Each of these arguments seem sensible, but they each rely on a different characterisation of students’ conceptions. For the teacher to know how to best teach to take into account learners’ ideas, they need to know which description of students’ conceptions applies.

Six dimensions of learners’ conceptions in science

As the reader may suspect, the different views of the nature of learners’ alternative conceptions are all supported by some research evidence. This suggests that learners’ conceptions about scientific topics are not all of the same kind, but rather they vary considerably (Taber, 2009). The teacher therefore needs to be aware of the kind of variation that occurs so they know how to respond in particular cases.

A person’s conceptions inherently vary in terms of degrees of acceptance, connectedness, multiplicity and explicitness. Each of these dimensions will be considered below. In addition to these dimensions, learners’ ideas vary in terms of how consistent they are with scientific models, and how similar they are to those of other students.

Degree of inconsistency with scientific models

One way in which learners’ alternative conceptions vary, is in terms of just *how alternative* they are. The author once taught a student who referred to ‘electron shields’ in atoms for what are normally referred to as electron shells. This student seemed to have a reasonable grasp of the nature of electron shells in atoms, but just used an alternative label. This was a rather trivial form of alternative conception, and may have actually been helpful in some circumstances (for example when thinking about ionisation enthalpies). However, other alternative conceptions may be alternative at a much deeper, conceptual level. A chemistry teaching colleague of the author thought that any sample of a strong acid would have a pH of 1. This knowledge ‘worked’ in the context of the actual practical work carried out in his classes - but showed a lack of (or more likely, failure to bring to mind long-neglected) understanding of acid strength and concentration.

Degree of explicitness of student knowledge

Sometimes we become aware of student conceptions because our students say or write something that is clearly not correct from a scientific perspective. Sometimes this is a statement that reflects a particular conception they hold as explicit propositional knowledge. That is, this specific idea is specifically represented ('stored') as part of their science knowledge.

However, many things that we elicit from students - as when we ask them questions in class - report ideas *generated* at that time in response to the specific question, rather than being the accessing and recollection of some specific notion that has previously been learnt and represented in memory. Consider a student who suggested copper was magnetic in response to a point posed in class. It may be that student had previously learnt (inappropriately) that copper was magnetic. However, it might be more likely the student had never considered this property of copper previously, but generated the suggestion from two ideas that had previously been learnt: copper is a metal (which it is) and all metals are magnetic (which they are not). It is even possible that the student had never *explicitly* considered the idea that all metals were magnetic before, but rather this was a tacit idea - something that the student had not even been aware they were primed to think until something in the classroom discussion provoked the thought.

This may seem fanciful, but there is strong evidence that much of our knowledge is tacit in this way - at the level of intuitions (diSessa, 1993). These intuitions, or intuitive knowledge elements, are represented in the brain at a level that is not directly open to conscious awareness, but which still influences how we perceive things, and understand them (see the Chapter '*Tacit Knowledge in Science Education: the role of intuition and insight in teaching and learning science*'). More research is needed into these kinds of aspects of knowledge, sometimes called phenomenological primitives, or p-prims. It is believed that we all have a large repertoire of these intuitions that we apply without even realising it when making sense of the world. Sometimes students can tell us what they think in a particular situation, without seeming to be able to explain their reasoning - as they are just activating their intuitive knowledge (Watts & Taber, 1996).

Such intuitions are not verbal, but to talk and write about them we have to put them into words. So, for example, people tend to know, or expect, that getting close to some source leads to a stronger effect. So we are not surprised that the fire feels hotter as we get closer, or the sound is less intense as we move away from the loudspeaker (as early life experiences lead us to expect such a pattern). It is common when asking students to explain the seasons that many will suggest that Summer is the time when the earth gets closest to the Sun in its elliptical orbit. Probably students have not been taught that, and perhaps had never even thought it before, but when asked a question about the seasons this intuition or intuitive knowledge element may be triggered. The broader 'more effect when closer' intuition is *generally* sound, but in this case its application leads to an alternative conception.

Degree of multiplicity of student knowledge

At first sight it may seem foolish to think two inconsistent things. Indeed the human brain seems to have evolved to prefer to maintain coherence between our different ideas. However, it is often possible to elicit from a student several ideas which seem to be inconsistent or even directly contradict. Of course, things that seem contradictory from the teacher's perspective do not always seem so from the student's perspective. For example, sometimes students will see as quite different phenomena what the science teacher conceptualises as different examples of the same basic phenomenon. So students may seem to change their minds about some science concept according to the context in which we ask the question (Palmer, 1997) - but from the students' perspectives different principles apply in the different situations. To make good sense of student thinking, we need to explore their ideas in their own terms.

Students may also offer alternative explanations for the same phenomenon if they feel that several complementary explanations are allowed. This is not so strange, as in science we often deal with complex phenomena with multiple causes, and indeed may recognise different levels of explanation. For example, we might discuss an animal eating in terms of instinctive drives, overall energy requirements, and specific metabolic processes.

A particular feature that some research has uncovered is how students may be able to learn scientific ideas in class, and reproduce them in formal tests, whilst retaining quite different and alternative conceptions they use in everyday discourse (Solomon, 1983). So a student may talk in the playground about exercise giving them energy, even though in the classroom they 'know' that exercising requires an energy source.

Degree of connectedness of student knowledge

As human beings we know about all kinds of things. Some of our knowledge is highly integrated, especially when we have expertise in a topic. As science teachers we are aware that certain ideas, maybe conservation of energy or natural selection, apply across a great many topics, and we tend to see the links between different things we teach. Students have spent less time studying and thinking about the science, and their knowledge tends to be less well organised and integrated than that of an experienced teacher. Indeed some of their conceptions may be more or less isolated fragments of knowledge - little 'islands of knowledge' - that they do not see as significantly linked to anything else.

Other ideas, however, become firmly linked into networks that can become mutually reinforcing. One common alternative conception that relates to chemistry learning is the idea that atoms want, or need, to have full outer shells (or octets of electrons). Students relate this idea to a wide range of notions about chemical reactions, chemical bonding, stability of different chemical species, patterns of ionisation enthalpies and so on (Taber, 2013a). Students usually acquire the conception quite early in their chemistry learning, and it may influence (and distort) later learning in a range of core topics (See the Chapter '*Teaching and learning chemistry*'). Students often find it difficult to reject this conception, even when they are taught that it is not a helpful notion, because they have already constructed an extensive conceptional framework around it.

Degree of commitment to student knowledge

Students are strongly committed to some of their alternative conceptions. In effect they have come to 'believe' the conception as an accurate fact about the world (see the Chapter '*Beliefs and Science Education'*). However, many student conceptions are more tentative. Sometimes students are perfectly happy to be told they have got something wrong, and to modify this aspect of their thinking. Many ideas elicited from students are not so much stable and committed conceptions but better considered conjectures - notions they are exploring and testing out. That of course is something to be encouraged in future scientists. Students may readily abandon many of these conjectures when they see, perhaps with the teacher's help, that they have limitations.

However, some other ideas may be committed to so strongly that it is very unlikely that any amount of telling or presentation of argument will persuade the students that their conceptions are wrong. People are generally very good at finding evidence that seems to support their ways of thinking and reasons to dismiss or see as flawed any counter arguments (Nickerson, 1998).

When students do not have any strongly committed conceptions relating to a particular topic, they may well consider and explore a range of alternative possibilities - perhaps shifting from one to another. This is one basis for finding students sometimes have manifold conceptions of the same topic as suggested above.

Degree of commonality of student knowledge

A final dimension to consider is how common students' conceptions are. At one level each student has a unique personal history of learning experiences. However, all students live in the same physical world, and have similar biological apparatus for exploring and finding out about it. Moreover, in any school or college many of the students will have been brought up in the same cultural environment and they will often share the same language.

Not surprisingly, then, research suggests that some alternative conceptions are very common. The majority of people have difficulty learning about the physics of force and motion, because most people think that an object that is moving must be subject to some kind of force in the direction of motion (Watts & Zylbersztajn, 1981). Even after learning about Newton's principle of inertia (the first law of motion), people often get questions about this topic wrong because intuitively they reject the physics. In most science topics explored, researchers have found examples of common alternative conceptions - that is where many students of a certain age seem to have much the same alternative conceptions.

However, it is also possible to find students reporting ideas that do not seem to be reported in the literature, and are not shared by any of their classmates. One student the author taught had her own understanding of what the charge symbols (such as the '+' in Na^+) were meant to mean which was not only quite different from the understanding of her teachers, but also - it seemed - all her classmates (Taber, 1995). As learning is interpretive, incremental, and iterative, there is always potential for individuals to form idiosyncratic ideas based on their own unique history of experiences - but the common experience and discourse of the community tends to act as something of a brake on this, and channels most of our thinking to be aligned with those around us that we regularly talk and listen to. Consequently, as teachers, we face both common alternative conceptions, many of which are discussed in published studies, and more rare examples - which often have not been reported in the literature.

Conclusion: what's a teacher to do?

This discussion of the diverse nature of learners' conceptions may not seem very helpful in deciding whether teachers should (a) ignore, (b) challenge or (c) seek to develop learners' alternative conceptions. All three of these options seem sensible *sometimes*.

The teacher therefore needs to read about the literature on the topic being taught, and find out more about the particular conceptions that have been discovered in research and what is recommended in various cases. However, even more importantly, the teacher needs to maintain a dialogue with her students, to find out just what ideas her students are using to make sense of teaching.

A major part of effective science teaching is making judgements about how to respond to learners' ideas - which ones can be best ignored, which are worth spending time challenging with demonstration and arguments, and which should be seen as useful starting points for moulding towards more scientific accounts of the world. The best response to the 'same' alternative conception may even be different in different cases. Teaching science well is very challenging as it can only be planned so far in advance - much of the expertise relates to being able to make decisions within class about how to respond to particular ideas we elicit from students. The decisions we make in such work should not be seen as definitive either, but seen more as based on hypotheses to be tested in the classroom, where - like good scientists - we collect evidence to evaluate our conjectures about student thinking and revise them when indicated by new evidence.

A good science teacher is therefore not just an expert on the science to be taught, but is a clinician in the classroom, a science learning doctor: constantly diagnosing student thinking, responding to it, evaluating this process, and revising the treatment of the topics as needed. This is difficult and highly skilled work. It can also be extremely fascinating, highly motivating, and - when we start to see progress in students' scientific thinking and understanding - intensely satisfying.

Recommended Further Reading:

Driver, R., Rushworth, P., Squires, A., & Wood-Robinson, V. (2013). *Making sense of secondary science: Research into children's ideas* (2nd ed.): Routledge.

Taber, K. S. (2014). Student Thinking and Learning in Science: Perspectives on the nature and development of learners' ideas. New York: Routledge.

References

diSessa, A. A. (1993). Towards an epistemology of physics. Cognition and Instruction, 10(2&3), 105-225.

Driver, R., & Oldham, V. (1986). A constructivist approach to curriculum development in science. Studies in Science Education, 13, 105-122.

Duit, R. (2009). Bibliography - Students' and Teachers' Conceptions and Science Education. Kiel, Germany: IPN - Leibniz Institute for Science and Mathematics Education.

Gilbert, J. K., Osborne, R. J., & Fensham, P. J. (1982). Children's science and its consequences for teaching. Science Education, 66(4), 623-633.

Kind, P. M., & Kind, V. (2007). Creativity in Science Education: Perspectives and Challenges for Developing School Science. Studies in Science Education, 43(1), 1 — 37. doi: 10.1080/03057260708560225

Lakoff, G., & Johnson, M. (1980). The metaphorical structure of the human conceptual system. Cognitive Science, 4(2), 195-208.

Miller, A. I. (1986). Imagery in Scientific Thought. Cambridge, Massachusetts: MIT Press.

Nickerson, R. S. (1998). Confirmation bias: A ubiquitous phenomenon in many guises. Review of General Psychology, 2(2), 175-220.

Palmer, D. (1997). The effect of context on students' reasoning about forces. International Journal of Science Education, 19(16), 681-696. doi: 10.1080/0950069970190605

Solomon, J. (1983). Learning about energy: how pupils think in two domains. European Journal of Science Education, 5(1), 49-59. doi: 10.1080/0140528830050105

Taber, K. S. (1995). Development of Student Understanding: A Case Study of Stability and Lability in Cognitive Structure. Research in Science & Technological Education, 13(1), 87-97.

Taber, K. S. (2003). Responding to alternative conceptions in the classroom. School Science Review,, 84(308), 99-108.

Taber, K. S. (2005). Learning quanta: barriers to stimulating transitions in student understanding of orbital ideas. Science Education, 89(1), 94-116.

Taber, K. S. (2009). Progressing Science Education: Constructing the scientific research programme into the contingent nature of learning science. Dordrecht: Springer.

Taber, K. S. (2011). The natures of scientific thinking: creativity as the handmaiden to logic in the development of public and personal knowledge. In M. S. Khine (Ed.), Advances in the Nature of Science Research - Concepts and Methodologies (pp. 51-74). Dordrecht: Springer.

Taber, K. S. (2013a). A common core to chemical conceptions: learners' conceptions of chemical stability, change and bonding. In G. Tsaparlis & H. Sevian (Eds.), Concepts of Matter in Science Education (pp. 391-418). Dordrecht: Springer.

Taber, K. S. (2013b). Modelling Learners and Learning in Science Education: Developing representations of concepts, conceptual structure and conceptual change to inform teaching and research. Dordrecht: Springer.

Taber, K. S. (2015). Prior Knowledge. In R. Gunstone (Ed.), Encyclopedia of Science Education (pp. 785-786). Berlin-Heidelberg: Springer-Verlag.

Vygotsky, L. S. (1934/1986). Thought and Language. London: MIT Press.

Watts, M., & Taber, K. S. (1996). An explanatory gestalt of essence: students' conceptions of the 'natural' in physical phenomena. International Journal of Science Education, 18(8), 939-954.

Watts, M., & Zylbersztajn, A. (1981). A survey of some children's ideas about force. Physics Education, 16(6), 360-365.