Joining up the thinking: how science 'learning progressions' could address problems inherent in primary–secondary transition

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ABSTRACT Dips in pupils' science attitudes and performance when they transfer from primary to secondary school in England are well established. They have been related to a variety of factors, including repetition of science content at year 7 and differences in the pedagogical approaches taken by primary and secondary teachers. One potential way forward would be to use data from research studies that have surveyed how pupils' science thinking develops across key stage 2 (7- to 11-year-olds) and key stage 3 (11- to 14-year-olds). These 'learning progressions' can provide continuity that takes into account pupils' changing science concepts over the transfer period and so help ease transition.

Setting the scene: dips in attitude and performance are related to transition

For some years it has been established that when pupils in England move from primary to secondary school they tend to lose interest in science – there is a pronounced dip on transfer from year 6 to 7 at age 11. It cannot be argued that this is wholly due to the period of adjustment associated with changing schools since interest continues to decline from year 7 to 9. Moreover, in English and mathematics the same pupils experience less of a dip in interest, or no dip (Barmby, Kind and Jones, 2008; Galton, Gray and Rudduck, 1999). The most recent Trends in International Mathematics and Science Study (TIMSS) in 2011 confirmed the pattern of previous reports, with pupils in England showing less interest in year 9 science compared with year 5 (although this was also the case for mathematics). Similarly, fewer year 9s than year 5s felt 'engaged' during science lessons (Sturman *et al*., 2012).

Reported reasons for dips in interest include the repetition of content that pupils experience when they are taught science at secondary level. Many start year 7 excited by the prospect of learning 'real science' in purpose-built laboratories. But the reality is that much of what they are taught in year 7 they already know from primary science lessons. It might seem surprising that such repetition exists, but secondary teachers have reasons for repeating ideas that they see as central to scientific understanding. Since year 7 pupils will come from a variety of primary feeder schools, despite there being a common programme of study for key stage 2 (7–11 years), individual primary teachers exercise autonomy and deliver varied curricula, resulting in pupils arriving at year 7 with a variety of different amounts of science knowledge and expertise. This has especially been the case since the abolition of the key stage 2 national tests (SATs) in 2009. This diversity of prior experience is sometimes allied with a view taken by secondary science teachers that primary science somehow lacks value, partly because it is rarely taught by science specialists. Therefore, they not infrequently are of the opinion that all secondary science teaching must begin at a base level in order that all pupils can grasp the fundamentals, despite the fact that many are already knowledgeable young scientists.

Other reasons for the dips in interest shown by year 7 (age 11) pupils relate to the differences in the ways in which science is taught in secondary compared to primary schools. As mentioned above, their expectation is usually that they will be experiencing authentic, engaging and practical science taught by expert scientist-teachers. They are disappointed to find that much of secondary science is written work, partly due to the curricular demand to teach a set body of conceptual knowledge. When practical work *is* carried out it is often accompanied by the traditional writing-up of experiments, which pupils tend to find tedious (Galton, 2009). Also, there are differences in the pedagogical approaches taken by primary and secondary teachers that impact on pupil attitudes. Particularly, during primary science lessons it is the norm for pupils to work in small, collaborative table groups, and the change to more didactic, teacher-led approaches to science can come as a disappointment (Moore, 2008).

In parallel with drops in interest, there are, perhaps unsurprisingly, concomitant drops in science attainment at the point of transfer at the start of year 7 that continue into successive years. Temporary dips in attainment across subjects are common as pupils adjust to their new school but have usually abated by the end of the first term in year 7. However, a significant minority, perhaps 10%, suffer more sustained dips in attainment that last at least until the end of year 9 (age 13) (Chedzoy and Burden, 2005). This manifests itself as an apparent regression in performance, with some pupils leaving year 9 being assigned lower National Curriculum levels than they achieved three years ago in year 6. This regression does not occur so often in English and mathematics (Braund, 2009). Returning to the TIMSS 2011 survey (Sturman *et al*., 2012), when pupils in England were asked how confident they were in their scientific abilities, more year 5 pupils than year 9 expressed a positive response. This confidence was not unfounded since the pupils who were the most confident were also the highest achieving in the conceptual test section of the survey. Drops in achievement were also confirmed – the year 5 cohort that were surveyed in 2007 attained comparably lower when they took the 2011 test as year 9 pupils: '*Cohort analysis… suggests that secondary schools in many countries, including England, may not capitalise effectively on the earlier mathematics and science achievement of their pupils at primary school*' (Sturman *et al*., 2012: 1).

Aside from regressions in performance after transfer, the TIMSS survey also threw the spotlight onto English year 5 pupils' overall levels of performance since 2007. Despite English primary schools' attainment scores being above the international average, there was a marked reduction in the achievement of year 5s in the 2011 study compared with the preceding 2007 study, placing English primary schools 15th in international ranking, down from the previous 5th. The Sturman *et al*. report notes that this decline coincides with the abolition of key stage 2 national tests in science in 2009.

Reasons for individual pupils' drops in attainment have included the sidelining by secondary science departments of primary schools' assessed science levels (Nott and Wellington, 1999). This ignoring of prior pupil data is sometimes associated with a reluctance to accept that primary teachers are able to 'properly' teach and assess science, discussed above. This attitude can be linked to a political need to baseline assess year 7 pupils at low levels, in order that sufficient progress can be demonstrated to Ofsted and other agencies. If pupils are judged to be at a low level on entry to year 7, then subsequent progress is easier to show, which puts the secondary school in a more positive light. These two factors together create a situation where year 7 pupils are invalidly assessed at lower levels than they were graded in year 6, and manifests itself as an apparent drop in performance on transfer. Other reasons are related to the previously discussed differences in pedagogy between primary and secondary teachers, which can turn pupils off science, and this loss in interest is quickly followed by a loss of performance.

Alongside these aspects, a major factor that has been cited for drops in attainment between the primary and secondary phases is a lack of continuity of learning, a problem that provides the rationale for the interventions presented later in this article. Despite the National Curriculum providing a smooth transition between science concepts in key stage 2 and key stage 3, secondary science departments tend not to take the content of primary science into consideration when planning their schemes of work. In fact, secondary teachers are generally ignorant of this content and see no reason to find out further details, which can be linked with the general discounting of primary science (Braund and Driver, 2005). This lack of coordination can lead to a repetition of primary content in years 7–9, or in some cases the assumption that specific content has been covered when it has not, creating a discontinuity that interrupts the smooth conceptual passage intended by curriculum designers. These issues have remained hidden, a situation not helped by the historical emphasis on pupils transferring from primary to secondary school being their social and emotional wellbeing and not their academic performance (Galton *et al*., 2003).

There clearly needs to be more communication between primary and secondary schools with respect to linking their respective curricula, and this has been attempted by the introduction of bridging units. These take different forms, but a typical approach is firstly to have close coordination between year 6 teachers and secondary science departments in order that each is fully aware of the content of the other's science curriculum. It can involve face-to-face meetings where schemes of work, resources, etc. are shared. This leads to the editing of each respective scheme of work in order to avoid both repetition and potential gaps in the content. The aim is to prepare year 6 pupils in the best way possible for their introduction to secondary science, both conceptually and also in terms of the cultural shift. This can take the form of day visits to secondary schools where year 6 pupils take part in engaging science lessons delivered by their future year 7 teachers. Alternatively, sequences of 'special' science lessons, designed to introduce some preparatory key stage 3 content, can be taught to year 6 by their usual primary teachers. However, evaluations of bridging units have identified problems, with primary teachers citing excessive teacher workload caused by planning bridging interventions, and secondary teachers noting that not all feeder primaries agree to undertake bridging units, which perpetuates the issue of mixed starting points for year 7 pupils (Galton *et al*., 2003). More generally, bridging units are merely local phenomena and no attempt has been made to roll them out at national level. Unfortunately, it appears that in recent years bridging units have fallen out of favour and are in decline (Symonds, 2015).

To summarise, problems on transfer from primary to secondary school can be categorised as drops in science interest and attainment and have been reported as being due to a variety of factors. The next section will discuss one potential way to address these issues, arguing that an emerging, presently little-known paradigm in science education could be utilised to foster pupils' interest and achievement at the point of transition.

What are learning progressions?

Pupils who start primary school at reception level think about the world differently from those who leave for secondary school in year 6. The mental faculties of reception pupils will gradually develop throughout the primary years as brain tissue matures and they learn more as a result of their interactions with the world. As a result of this progressive development, pupils' science concepts change because at any one point in time these concepts are only capable of being understood at a certain level of sophistication. Typically, it is rare for a primary school pupil to be able to appreciate gravitational forces in a true scientific sense, as invisible pulls that act on an object and which are the result of an interaction between two bodies – the object itself and the Earth. Between the ages of 5 and 7 years, gravity can be thought of as something that only acts on heavy objects, because perceptually, light objects appear not to possess the property of weight (such ideas are linked to the view that weight is a property of matter, not a force derived from the interaction of two bodies). At around 8 years, more sophisticated models are constructed, for example, the view that gravity can act on light objects but only if they are falling downwards (Russell, McGuigan and Hughes, 1998). At about the time when key stage 2–3 transition occurs at age 11 years, more abstract models emerge, such as gravity being an internal force present inside an object that pulls it towards the ground. The scientific view of the gravitational field of the Earth exerting an attractive force called weight on objects is usually only understood at 14–16 years, while appreciations of mutual attraction are rarer (Earth attracts object while object also attracts Earth with an equal and opposite force).

Clearly, these different ways of thinking about the same phenomenon are due to pupils' continually developing psychology – they are *learning progressions* (LPs). The National Research Council in the US has described LPs as maps of the possible routes that a pupil's thinking may take on the way to the final destination of successful learning of a science concept (National Research Council, 2012). The use of LPs to inform the planning of teaching is a recent innovation that first emerged from mathematics education about 10 years ago, and is currently becoming embedded in new curricula in a number of American states (National Research Council, 2012). The premise is that pupils do not always learn a particular science concept in a single conceptual leap; instead there are 'halfway houses' of partial understanding that are often useful learning targets that teachers should aim for. An important tenet is the view that new learning is always built upon already-existing concepts, which is relevant to key stage 2–3 transition and will be further developed later in this article.

Traditionally, subject experts have written science curricula as a sequence of progressive concepts that, although they increase in sophistication with age, may not take into consideration the way in which pupils' ideas naturally develop over time (Alonzo and Gotwals, 2012). The LP approach in contrast is embedded in research that has demonstrated these natural progressions. Curricula based on LPs attempt to present content in the same order in which pupils' concepts change as they pass through the different years of schooling, so that teaching becomes more in resonance with how learning naturally takes place. The aim is to go beyond a view of learning as a gradual accumulation of concepts to allow a deeper, more connected process.

Table 1 shows a learning progression for the topic *Earth in space* that spans the primary years and crosses the point of key stage 2–3 transition. It is based on pupils' concepts as reported by a number of different studies from a variety of countries, and so represents a distillation of ideas from diverse sources. Although the progression is subdivided into columns by age, note that these ages are 'typical' and do not represent firm boundaries. Normally, within the same classroom, different pupils' thinking will lie at different stages of the LP, which will be in line with how well developed the conceptual faculties are of different pupils. This may be apparent by general measures of 'ability', so teachers could predict how far along the progression a particular child is by considering other attainment data. In the same class, for instance, most of the pupils may lie at a point in line with their chronological age (as given in Table 1), while some will be operating at a level typical of lower age groups, and others at one of higher age groups. In reality, however, the situation may be more complex where the same pupil can exhibit thinking across mixed levels of progression; for example, a pupil who has accepted that the Earth is spherical (typically ages 10–11 years) may also have constructed a geocentric model of the solar system with the Earth at the centre (typically 5–9 years).

Teachers who plan using an LP approach will begin a topic by eliciting the ideas that pupils already have in order that each individual can be placed at the appropriate level on the LP. As stated in the preceding paragraph, the same pupil may be at different levels for different concepts. Once this is established, work can be appropriately differentiated according to level, with pupils who are currently operating at a lower level receiving support so they can progress to the next higher level, and so on. A general principle is that lower level concepts need to be firmly in place before the higher levels can be accessed. Therefore, the sequence of lessons needs to reflect the order in which ideas naturally appear, as given by the LP. However, learning does not always occur in this linear fashion for all pupils and so LPs are not 'written in stone', they are merely hypothetical trajectories that have been summarised from research that has shown that learning tends to progress in certain directions (Plummer and Krajcik, 2010).

One aspect of an LP approach that might appear controversial is the use of halfway-house concepts as secure, intermediate stepping-off points for further learning. Referring to Table 1, pupils at the lower point on the LP probably do not yet know the names of all the planets, or that they are arranged in a particular order in space from Mercury to Neptune. If a pupil is able to draw a picture of the solar system that correctly names the planets but has the order incorrect, then this is an acceptable halfway-house point from which the correct order can subsequently be taught. The acceptance of erroneous science is arguably not good practice, but nevertheless has the advantage of easing pupils' thinking along a direction in which it would naturally flow – all teaching has done is accelerate the progression that would likely have taken place on its own, over time, as pupils work their way through the science curriculum. At any rate, much of science

Table 1 How learning progresses: Earth in space (Allen, 2016)

	Typically 5–7 years	Typically 8–9 years	Typically 10–11 years
Shape of the Earth	The Earth is either flat, a two-dimensional disc or a hollow sphere containing a flat area where we live.	The Earth is either flat, a two-dimensional disc or a hollow sphere containing a flat area where we live.	The Earth is spherical.
Relative sizes of heavenly bodies	The Earth, Sun and Moon are the same size.	Difficulties placing Earth, Sun and Moon in the correct order of size.	Difficulties placing Earth, Sun and Moon in the correct order of size (though the Sun is larger than the Earth or the Moon).
Reasons why day and night occur	The Sun rises and sets every day. Night occurs because people need to go to sleep. The Sun moves horizontally in a straight line across the sky during the course of a day. Difficulties in drawing shadows relative to the Sun's position in the sky.	The Sun rises and sets every day. The Sun moves horizontally in a straight line across the sky during the course of a day. The Sun moves across the sky because the Sun orbits the Earth. Difficulties in drawing shadows relative to the Sun's position in the sky. The Earth orbits the Sun every 24 hours.	The Sun moves horizontally in a straight line across the sky during the course of a day. The Sun moves across the sky because the Sun orbits the Earth. The Earth orbits the Sun every 24 hours. The Earth spins on its axis (although the fact the Earth spins once every 24 hours is not well known).
Earth's orbit	Models are usually geocentric (Sun orbits the Earth).	Models are usually geocentric (Sun orbits the Earth).	Models are usually heliocentric (Earth orbits the Sun), but can be geocentric.
Moon's orbit		Moon rises and sets like the Sun. That the Moon orbits the Earth is not well known.	Moon rises and sets like the Sun. That the Moon orbits the Earth is not well known.
Moon's phases	The Moon can take on different shapes.	The Moon can take on different shapes. Caused by the Earth's shadow (eclipse model).	Caused by the Earth's shadow (eclipse model). Starts to understand the cycle of phases.
Earth's seasons	That day length and the Sun's altitude in the sky vary with season is not well known.	That day length and the Sun's altitude in the sky vary with season is not well known. Seasons are caused by the Sun moving closer to or further from the Earth over the course of a year.	That day length and the Sun's altitude in the sky vary with season is not well known Seasons are caused by the Sun moving closer to or further from the Earth over the course of a year.
Planets	Draws pictures of the solar system with the planets and Sun randomly arranged.	Earth is a planet. Problems with naming all the planets, placing them in size order, or recognising pictures of planets.	Earth is a planet. Able to draw the solar system reasonably accurately, but problems with naming all the planets, placing them in size order, or recognising pictures of planets.
Stars	Unable to differentiate between a planet and a star. That the stars are still present in the daytime sky is not well known.	Unable to differentiate between a planet and a star.	Unable to differentiate between a planet and a star. Stars are smaller than the Earth.

education has always been based on the teaching of simpler models at younger ages, which are only at best partly scientifically correct, that are then refined later on in a pupil's school career. For example, at key stage 2 pupils are taught that chemical reactions are examples of irreversible change, but at key stages 3 and 4 are told '*forget what you learned in primary school; many reactions are reversible*'.

Using learning progressions to help alleviate the problems of transition

As was discussed earlier, the problems of dips in pupil interest and achievement have been linked, with other factors, to a loss in continuity of learning across key stages 2 and 3 when pupils change school. Despite the National Curriculum providing a seamless conceptual progression across the key stages, discontinuities at the point of transition do exist and can be jarring for pupils as they experience repetition of content or the assumption of knowledge that was not actually covered in primary school. This leads to the view that science is either boring or too difficult, culminating in negative attitudes towards the subject and concomitant underachievement. Adopting a learning progression approach to the planning of teaching could potentially be a positive step that reduces this jarring effect, making for a gentler transition that might lessen the severity of the dips.

Largely, although not exclusively, the onus needs to be on secondary science departments to try to resolve the problems of transition discontinuity. One reason why young secondary pupils find science so difficult is the increase in the complexity of concepts from year 6 to year 7. This is in many ways unavoidable, given the nature of science education, which is presented within a spiral curriculum that revisits the same topic areas in ever more complex ways. Ideally, teachers need to make secondary science a little more understandable for pupils. The literature contains an exhaustive number of examples of engaging pedagogies that have systematically been shown to help learning – for instance, *School Science Review* has always been a rich source of pedagogical ideas. However, alongside effective teaching methods there needs to be some theoretical element that links them together in a holistic way. Aside from providing engaging opportunities, learning progressions could provide this 'glue' that would help science teachers plan lessons that take into account pupils' developing psychology.

Because they are cross-phase, LPs link learning between year 6 and 7 by providing a common template from which both primary and secondary teachers can operate. Used in conjunction with bridging units, feeder primary schools can pass on LP information about individuals at the point of transition that is 'low stakes', in the sense that it is free from the political effects that the old levels system had. Since LPs are not used to formally judge schools, they would allow for a more honest appraisal of pupils' abilities and so help year 7 teachers cater for their academic needs. Year 7 teachers can use the LP approach to further assess their pupils' understanding at transition and so plan work that is tailored to their current level of development. An additional bonus would be that secondary teachers would become more aware of the content and learning that takes place prior to transition; consequentially, primary science may be held in more esteem than is currently the case.

In the USA, partly in response to criticism of a lack of organisation of science education across the different years of schooling (there is no National Curriculum), the Next Generation Science Standards (NGSS) are being implemented in some states. Providing continuity is achieved by taking into consideration how pupils' ideas develop over time by using a learning progression approach. The Framework document (National Research Council, 2012: 26) explains the rationale for the embedding of LPs clearly:

If mastery of a core idea in a science discipline is the ultimate educational destination, then well-designed learning progressions provide a map of the routes that can be taken to reach that destination ... learning progressions may extend all the way from preschool to 12th grade [aged 17–18] and beyond—indeed, people can continue learning about scientific core ideas their entire lives. Because learning progressions extend over multiple years, they can prompt educators to consider how topics are presented at each grade level so that they build on prior understanding and can support increasingly sophisticated learning. Hence, core ideas and their related learning progressions are key organizing principles for the design of the framework.

The writers of this new curriculum have realised that an LP approach has value, and have taken a significant risk, given that the LP movement is in its infancy and there is a dearth of evidence so far that LPs have a positive and lasting effect on pupil learning. Nevertheless, the early signs are that the approach is potentially a powerful tool for solving long-standing educational problems (Duncan and Rivet, 2013), and as it becomes more well known in England it cannot help but encourage more teachers to 'join up' their pupils' thinking.

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