

UNIVERSITY OF BIRMINGHAM

LEARNING STUDY

**THE POTENTIAL OF LEARNING STUDY TO ENHANCE INITIAL TEACHER EDUCATION AND CONTINUED
PROFESSIONAL DEVELOPMENT AT THE UNIVERSITY OF BIRMINGHAM**

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Executive Summary

The potential of learning study to enhance initial teacher education and continued professional development at the University of Birmingham

Learning Study is an approach to teacher development that employs a plan – teach – review cycle, and so on. In Learning Study teachers become researchers of their own practice. It is a subset of Japanese Lesson Study, and is distinguished from Lesson Study by the use of Variation Theory to assist in planning, teaching and evaluation. Variation Theory offers a framework to analyse the lesson subject content and focuses teachers' attention on what is called the object of learning. It offers a means of lesson analysis which is compatible but different to Bloom's taxonomy and also different, but complementary, to analyses which examine the methods of teaching.

The four key elements of Learning Study are:

- A small group of teachers working collaboratively to plan a 'research lesson'.
- Use of Variation Theory to plan, teach and evaluate the 'research lesson'.
- An opportunity to refine the 'research lesson' and compare lessons to give an indication of the success of the approach.
- Information about specific groups of learners is collected and used in planning and evaluating.

The literature reviewed in this report points to Learning Study having significant potential in both initial teacher education (ITE) and continued professional development (CPD). Learning Study offers the potential to develop our already excellent programmes by allowing us to develop the four key aspects described above. It also provides a means by which schools and the University of Birmingham can work together in a way that is firmly school based. Learning Study offers clear roles for teachers, mentors, trainee teachers and University tutors. It makes use of teacher expertise but also provide a clear role for University tutors involvement as researcher-facilitators. The researcher-facilitators offer subject specialist guidance on the use of Variation theory and on the procedures for Learning Study but it is teachers and trainee teachers who are the main researchers.

In the report I suggest there are three models for ways of the University of Birmingham including Learning Study in their initial teacher education provision: integrative; periodic; and wholesale. In the report I evaluate these three models and suggest that for our PgDipEd mainstream provision in the short term adopts the integrative approach, where elements of Learning Study are included in a developmental and gradual way. This would allow the approach to be trialled in a small way to begin with.

The periodic use of Learning Studies, in a way similar to the Case Study shared in the report, where there is a deliberate and time limited approach to 'kick start' Learning Study in a school, could be developed as part of our CPD provision or as part of our ITE SD provision. Such an approach would facilitate groups of teachers, including from different schools, to work together.

In the report I have touched up the idea of a wholesale adoption of Learning Study for our teacher education. However, Learning Study addresses only part of what trainee teachers need to know, understand and do. Thus it is my view that Learning Study could not be the main mechanism for ITE.

A benefit of Learning Study is that it is a means of both developing teachers' knowledge and understanding of learning process, and a means of researching the classroom context. Each Learning Study has a 'knowledge product' and this could be shared in a relatively simple way across the whole University of Birmingham partnership. Thus Learning Study has benefits to both the teachers involved and also a wider group of teachers.

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1 Goals of this report

Learning study is a form of teacher research where a research lesson is planned and evaluated collaboratively with other teaching colleagues. Some preliminary work is done to identify what students know and understand about the topic. The lesson is then taught, initially by one teacher, and observed by other teachers in the group. The lesson is then reviewed and adjustments are made prior to the second teacher teaching it to a different group. Variation theory (Marton and Booth, 1997), a theory of learning, is used to frame the planning and teaching process. This final point is what distinguishes learning study from lesson study (Stigler and Hiebert, 1999).

In this report I will review research that has been done on learning study and variation theory with the overall goal of exploring its potential as a means of teacher education and teacher development within the School of Education at the University of Birmingham. A particular focus here is to explore how learning study might be used within science initial teacher education (ITE) and a goal is to pilot the approach in this subject. Learning study approaches also offer potential as a means of lecturer development within the context of Higher Education and this is something that will be touched upon later in this report. There are, however, challenges with trialling learning study within the University, amongst other things it is generally seen as being very time consuming with multiple collaborative meetings between teachers and researchers part of the approach. Thus there are resource implications for its implementation. Three different models for implementing learning study will be evaluated and a recommendation made about the best way ahead. A key consideration in this evaluation will be how to work within resource constraints and how to build on existing provision in a sustainable way.

Most previous work on learning study has been done in Hong Kong and Sweden. While there have been a good number of studies within a phenomenographic framework done in science education, many have used variation theory outside of the learning study framework. Thus there is significant scope to explore learning study in the context of ITE and in particular within science ITE. Involvement in learning study would allow the University of Birmingham to take a lead within the UK in this area and to demonstrate a commitment to relevant school based research and teacher development.

A key feature of learning study is that it is done by teachers under the guidance of a researcher/facilitator. Thus teachers themselves become researchers of their own practice. Learning study, thus, has the potential to frame a way of working between schools and the University of Birmingham. The roles adopted by teachers and researchers in learning study are compatible with the changing relationships between schools and universities in England. In particular learning study emphasises that it is teachers who are the researchers of their practice, while university researchers offer guidance on the learning study framework.

The research examined below demonstrates that there are benefits to teachers, both trainee and in post, of being involved in learning study. Teachers have been found to develop their understanding of teaching and learning, as well as developing insights into subject pedagogy and students' learning in their subject. The knowledge product, which is the subject specific research output from learning study, is one outcome of the approach. The knowledge product can be articulated and shared and become part of both teachers' knowledge and also institutional knowledge. This sharing of professional knowledge is a key part of the learning study process and the developing network of

schools collaborating with the University of Birmingham offers a platform for the building and sharing of this professional knowledge.

In this report I will articulate the key features of learning study and variation theory, and evaluate its potentials to be used at the University of Birmingham. The main questions to answer are:

1. Is there a convincing case for learning study approaches to be developed at the University of Birmingham?
2. How can learning study be adapted to be used at the University of Birmingham in ITE? What models are there for its introduction?
3. In what ways can learning study be introduced to the wider University of Birmingham partnership of schools?

2 Describing learning study and identifying its key features

In learning study a small group of teachers (perhaps three or four) work collaboratively with a researcher/ facilitator to plan a research lesson. This research lesson is then taught and evaluated. There are two main ways of arranging learning studies. Firstly, in line with Japanese lesson study (Stigler and Hiebert, 1999), teachers collaboratively plan a lesson and one member of the group teaches the jointly planned lesson while other members of the group observe it. A further meeting is subsequently held where the plan is evaluated and revised and then another member of the group teaches it. Thus there is a cycle of planning teaching-reviewing-teaching-reviewing which allows for ideas to be explored in depth. The key point here is that the research lesson is taught successively to different groups of students. The second way of arranging the Learning Study is to adopt a 'design experiment' (Brown, 1992; Collins, 1992) approach where there is an experimental group, which will be subject to a lesson planned using variation theory, and a control group who will not. Similarities and differences between the experimental and control groups are then compared and explanations offered based on variation theory.

In both the lesson study and the design experiment inspired modes of learning study a key point is that learning is at the heart of learning study. It involves the learning of both students and teachers:

"Such a study is a learning study in two senses. First, it aims at bringing learning about, or more correctly, at making learning possible. The students will thus learn, hopefully. Second, those teachers involved try to learn from the literature, from each other, from the students, and not least, from the study itself." (Marton and Morris, 2002)

Collaboration between colleagues is an essential part of learning study and there is a significant degree of teacher ownership in the process. Importantly teachers become researchers who generate knowledge rather than being objects of study (Lo, 2009). Carlgren (2012) argues that learning studies are best described as clinical research of the particular, and explains that studies draw on teachers' experiences, rely on theory and examine learning problems that are specific to a particular group of students. This reliance on teacher experience, knowledge and understanding, however, does present some challenges when the approach is used with trainee teacher, who will inevitably have little experience to draw upon. This examination of the particular mean that individual learning studies are case studies (Lo, 2009), which means that findings need to be carefully interpreted if they are to be useful in other contexts.

As mentioned above what distinguishes learning study from lesson study and other collaborative approaches is the use of a learning theory, variation theory (Marton and Booth, 1997), as a framework. Central to variation theory is that learning involves the learning of *something*, this something is known as the object of learning (Marton and Booth, 1997; Marton and Lo, 2007). Basically the object of learning is a clear statement of the content to be learned and the capacity that the teacher wishes to develop. The object of learning is seen as being the 'point of departure' for planning lessons (Lo, 2009). This is an important distinction because other theoretical frames, such as constructivism, are general and do not offer the teacher help in looking at how to teach particular content. From constructivist perspectives, for example, the *method* of teaching is often the starting point for the planning process (Ljung-Djärf et al., 2014).

While the overall planning process in learning study is built on the object of learning, teachers are free to modify the plan if necessary and teach according to their personal style (Pang and Marton, 2005). This makes it difficult to compare studies because it may be that there is a substantial variation between the enacted lessons of individual teachers even though planning may have been done jointly. However, what is common is that variation theory will have been used to analyse the object of learning and to plan for its teaching.

Learning studies are characterised by their use of a range of sources of data. For example Pang and Marton (2005) used pre- and post-test written tasks; video recorded lessons with verbatim transcriptions; post-test interviews with students; data from preparatory meetings and interviews with the teachers; lesson plans; and field notes. These data sources are used to identify students' and teachers' understandings of the object of learning, and teachers' approaches to teaching the object of learning. The sources contain valuable information for teachers about how students' understanding the object of learning before teaching, during teaching and after teaching.

The knowledge product from a lesson study can include lesson plans which details teacher and student actions; activities undertaken; and how students might respond (Runesson and Gustafsson, 2012). The knowledge produced from a learning study focuses on the object of learning, in particular teachers will have established a pattern of variation and invariance that can be shared following the study. Patterns of variation used in teaching will be explained later in this report but an example of such a pattern of variation can be seen in Appendix 2.

3 What is the case for learning study at the University of Birmingham?

3.1 General case

Within England relationships between schools and universities are currently subject to a reorientation. Whereas historically universities have been commissioned by government to lead initial teacher education, there is an ongoing shift towards schools themselves leading teacher education and, in turn, commissioning the involvement of universities. This changing context presents both challenges and opportunities for university involvement in both ITE and CPD.

University researchers have sometimes been criticised for being out of touch with the school context, and this point brings into question the significance of their contribution. Learning study offers an alternative means of ITE and CPD where instead of professional development being done to and for teachers, Learning Study is done with and by teachers (Nilsson, 2014). In line with Stenhouse (see Elliott, 2012) teachers are conceived as researchers. As such being involved in learning study empowers teachers to undertake their own research within their own context. In building knowledge in their own context, teachers are also learning *about* the knowledge production process. Thus they are better able to independently research their own practice and make use of research findings in their classrooms. This argument also holds for other practitioner research approaches, such as action research. However, the learning study approach has two specific advantages. The first is that it is necessarily a collaborative enterprise, unlike action research which is not necessarily collaborative. The benefits of collaboration are that teachers are able to draw upon others experience of the specific objects of learning under the guidance of a researcher/ facilitator with specific knowledge of learning study. The second advantage is that learning study is framed by

variation theory, a learning theory, which has been shown to be substantially beneficial to teachers as they plan, teach and evaluate lessons.

Learning Study also seems to offer a powerful means of knowledge building across University partnerships. Runesson and Gustafsson (2012) found that teachers were able to use and build on knowledge produced in a Learning Study in a different context in their own teaching. Thus the knowledge product from learning study is potentially transferable to other contexts and learning from a learning study is generative. Thus, the reported outcomes from studies are such that those who have been involved in learning studies would be able to interpret them and appropriately apply them to in a different context. The sharing of the knowledge product is a necessary part of being involved in learning study and facilitates teachers' articulation of practice. An example of how such knowledge products could be presented can be found in Appendix 2.

There is a growing body of evidence from research that there are substantial benefits for students of teachers using learning study and variation theory in their planning and teaching. For example Pang and Marton (2005) found that the use of variation theory was associated with a 40% difference in the number of students who had gained a good grasp of economic ideas. According to Lo *et al.* (2005) in 25 out of 27 learning studies the gains made by weaker students were greater than for higher achieving students. Furthermore, Holmqvist *et al.* (2007) and Pang (2010) both found that learning study was associated learning beyond the teaching/learning context. In particular Pang (2010, p. 675) found that students in a group whose teachers had undertaken a learning study were "comparatively more able to sustain their ability to handle financial problems in novel situations over time than those in the lesson study group...". This evidence may be explained in part by how learning study brings objects of learning into focus by using variation theory (Lo and Marton, 2012; Ljung-Djårf *et al.*, 2014). It is likely that schools who are partners with University of Birmingham will be interested because of this research evidence and be willing to be involved to explore the potential of learning study to improve teaching and learning in their contexts.

Learning study also offers opportunities for teachers to learn from learners (Marton and Lo, 2007). In learning study student difficulties with curriculum content are seen as resources to be used in teaching. This philosophy, therefore, emphasises that the difficulties students have in learning are not as a result of limitations in their ability but because they have not yet been able to discern what is critical in the phenomena they are learning about. Thus the learning study approach is not deterministic in its view of what pupils can or cannot achieve. It also emphasises that teachers can do something about these difficulties. An additional benefit to learning study, reported by Lo (2009) and Runesson *et al.* (2011), is that teachers showed increased sensitivity to students' learning as a consequence of undertaking a learning study. Learning study offers a means for teacher to learn about their teaching, something highlighted by Hattie, (2009, p. 22) in his substantial review of literature:

The remarkable feature of the evidence is that the biggest effects on student learning occur when teachers become learners of their own teaching...

Curriculum change is frequent for teachers in secondary school and this currently is the case. Tan and Nashon (2013) explored how learning study can be used as a means of embedding a new curriculum in science education. Thus the Learning Study does offer a framework for teachers to examine new curricula, and presumable for new teachers to learn about curricula.

Holmqvist (2011) investigated how knowledge of variation theory influenced how teachers handled the object of learning. It was found that there were two developments seen in the teachers involved in the study. Firstly they developed their use of variation theory, including their ability to analyse the object of learning to identify the critical features. Secondly they developed how they handled these critical features in their teaching. Thus involvement in learning study is a CPD opportunity for practicing teachers and may offer a useful framework for University involvement in CPD in schools.

In this section I have developed arguments presenting the benefits of learning study. However, there are two concerns which need to be considered if learning study is to be developed at the University of Birmingham. The first concern is that there are opportunity costs associated with any introduction of learning study and that alternative approaches may offer at least as many benefits. The second concern is that there are issues with the introduction of learning study. Tan (2014), for example, raises the issue of how different parties understand the role of variation theory differently, and go on to use it differently.

3.2 ITE at the University of Birmingham

Davies and Dunnill (2008) reported how learning study was enacted across a cohort of trainee teachers. They found, in the context of initial teacher training, that learning studies were beneficial and practical to undertake. Furthermore, they found that learning study helped beginning teachers to develop their conceptions of teaching, in other words there is evidence that learning study can develop trainee teachers' thinking at an epistemic level. A key point here is that learning study has the potential to develop thinking about teaching and learning *within* the school context. However, Davies and Dunnill (2008) do point out that it is not possible to attribute learning about teaching to learning study alone when there are also other aspects to the course of which learning study was part.

Davies and Dunnill (2008) also report that trainee teachers found the collaborative context of learning studies to be very positive. Learning study offers a framework for structuring collaboration between experienced, inexperienced teachers and university tutors where each member has the potential to contribute, where each person's contribution is valuable and where knowledge is co-constructed.

A criticism by some is that there is a divide in initial teacher education between theory and practice. While this criticism is not universally accepted, learning study offers a means to bridge such a gap (Cheng, 2014). The reason for this is that a theory, variation theory, is used in the classroom context, thus integrating research into the classroom. This resonates with a renewed interest in university partner schools in research, and in particular action research. Furthermore, the trainee teachers become researchers and so begin to understand the knowledge production processes and this is something that is potentially beneficial throughout their career and which is in line with expectations at Masters level study. Elliott (2012) advocates a 'laboratory model' of learning to teach in which theory and practice are both included.

Ko (2012) and Cheng (2014) report how learning studies have been a module forming part of Bachelor in Education programme. A danger of such approaches is that Learning Studies are seen as separate, stand alone, approach which do not relate to the everyday work of a teacher.

3.3 Science education and science teacher education at the University of Birmingham

There is a limited number of science learning studies reported (there is a section giving more detail of specific articles later in this report).

In the science education courses at University of Birmingham there is a well-established procedure for lesson planning. This involves the identification of teaching topics, scrutiny of school schemes of work, the production of concept maps and then translating these concept maps in to Bloom's taxonomy framed learning objectives. The subsequent step is then for trainee teachers to take the learning objectives and identify appropriate learning activities. Variation theory offers a logical and research informed approach to developing a sequence of ideas to teach to students based on the object of learning. While it does not provide details of the activities it does offer a bridge from the learning object to the activities. Thus variation theory offers an additional framework for trainee teachers to analyse their planning and teaching.

As mentioned above the point of departure in learning study is the object of learning. Variation theory, therefore, offers a framework for trainee teachers which places the focus on the subject content rather than the method of instruction. It is my experience that some trainee teachers start their planning with an activity which they intend to use rather than with a detailed plan of the content they wish to teach, that is the object of learning. Thus variation theory offers a means of addressing this issue.

Furthermore, lesson planning at the University of Birmingham and in partner schools is usually framed using Bloom's taxonomy. While the taxonomy offers an important analytical approach learning objective framed in this way focus attention on a skill, such as describing or explaining, rather than focusing attention on the specific content. Therefore, learning objective phrased in this way can give the impression the skills is more important than the science content. This in turn suggests that skills, for example of describing or explaining, are somehow generic and can be removed from the content which is being dealt with. A re-emphasis on science content, through the use of variation theory, thus resonates with some changes made to the English National Curriculum and GCSE/GCE examinations where there is a renewed focus on content rather than generic skills.

Variation theory has the potential to be particularly useful in Science education because of the complex nature of the content. Taking one thing at a time, as suggested by variation theory, has the potential to reduce complexity (Nilsson, 2014). More details of variation theory are given in the next section.

3.4 Conclusions

The research evidence described above indicates that researchers have identified significant benefits to using variation theory and learning study, both generally as a means of teacher development, and specifically in the context of ITE. Translation of learning study to the English context, however, is not necessarily straightforward because of the difference between the cultural contexts in which the learning studies are undertaken, and differences between the challenges that need to be addressed in each context. For example my sense is that a particular challenge in the Hong Kong context is how to integrate theory and practice in initial teacher education. For science ITE at the University of Birmingham, this is not the most significant challenge to address. In our context developing new relationships and new ways of working with partner schools, while having a clear role for university involvement in ITE.

In the next section I will explore variation theory in more detail.

4 Variation theory: Key concepts explained

Variation theory is what distinguishes learning study from lesson study. Variation theory central to learning study. Tan (2014) identifies three ways in which variation theory has been used. Firstly it has been used to frame student learning. Secondly, and more frequently, it has been used as a tool in planning, teaching and evaluating research lessons. Finally it has been used to frame teachers' own learning. I would also suggest that variation theory offers a means of sharing professional knowledge by means of the 'knowledge product', which is the patterns of variation and invariance that are identified in a learning study.

A basic premise of variation theory is that because people are different, for example they have different life experiences and different amounts of background knowledge (Guo et al., 2012), they experience phenomena in different ways. Thus the idea of focal awareness is important because a student may focus on different parts of a phenomena to that which the teacher intended, and so learn something different to that which the teacher planned. One example which will be familiar to science teachers is that students may not interpret metaphors as teachers intend (Harrison & Treagust, 1996). For example Nilsson (2014) found that the metaphor of electron shells in chemistry was problematic.

There is some important vocabulary which is necessary to understand variation theory which I have touched upon above, but without explaining fully. So in the next section I will explain the meaning of the following core concepts: object of learning; critical aspects and critical features; patterns of variance and invariance; and space of variation.

4.1 Object of Learning

As explained above central to variation theory is the idea that learning always involves the learning of something, this something is known as the object of learning (Marton and Booth, 1997; Marton and Lo, 2007). There are considered to be three objects of learning. Firstly, the intended object of learning which is what the teacher plans to teach. Secondly the enacted object of learning is found in the lesson that is actually taught and finally the lived is the object of learning that is experienced by the students. Sometimes the lived object of learning is considered at three points: before teaching; during teaching and after teaching.

A further distinction made by Marton and Pang (2006) is between direct and indirect objects of learning. They point out that both aspects of the object of learning are necessary. The direct object of learning is the subject content that will be addressed in the lesson. The indirect object of learning is the capacity the teacher wishes to develop in the students. It might be helpful here to look at an example from science education provided by Cheng and Lo (2013, p. 5):

“‘Three phases of water’ is a direct object of learning. ‘Being able to recall the three phases of water’ is an indirect object of learning that is specific. ‘Being able to produce scientific explanations of everyday phenomena, such as the formation of mist, fog and dew using the three phases of water’ is an indirect object of learning that is general.”

Lo (2012) distinguishes the object of learning from learning objectives by indicating that a learning objective is the end point of learning but the object of learning is the starting point because it is based on where students are. I understand the reason for making such a distinction but practically a teacher needs to start somewhere with their thinking and planning. The relationship between learning objective and object of learning would need to be explored carefully in any practical outworking of learning study or variation theory.

4.2 Critical aspects and critical features

Critical aspect and critical features are empirically derived. They do not come from curriculum plans or from textbooks. This is because what is critical to one person may not be critical to another. What someone experiences during teaching is what comes into their focal awareness, and what comes into their focal awareness may be different. Thus it is important to establish what things are critical for a particular group of students.

I need to explain what critical aspect and critical features are, however. To give an example from Lo (2012) - if a teacher wishes to teach pupils about the colour red they can show an example of red object, such as a red apple. However, on its own a red apple does not teach about the colour red only as it also could be used to teach about apples and it is possible that a learner could focus on something other than that which the teacher wishes to teach. So in this example critical features are apple and red, whereas the critical aspects are colour and fruit. Elsewhere the language of dimension is used instead of aspect and the value is used instead of feature. I think that trainee science teachers may find it easier to think in terms of dimensions and values because this is language with which they are familiar.

4.3 Patterns of variance and invariance

Variation theory postulates “that for any specific object of learning there is a necessary pattern of variation and invariance that the learners must experience in order to appropriate the object of learning in question and thus by bringing out that pattern in the learning situation, the likelihood of that object of learning being appropriated is enhanced.” (Pang and Marton, 2005, p. 159). There is growing empirical evidence to support this claim (Pang and Marton, 2005).

Pang and Marton (2013, p. 1066) have articulated variation theory in terms of what they call a ‘basic conjecture’, which is “new meanings are acquired from experiencing differences against a background of sameness, rather than experiencing sameness against a background of difference.”. They point out that a large number of studies have supported this conjecture but there is a fundamental issue with the methodology of the studies in that the patterns are identified during and after the study, not before. Overall, patterns of variation have been found to lead to gains in outcomes for students (Runesson, 2005; Marton & Tsui, 2004; Marton and Morris, 2002).

Based on this conjecture teachers can make use of patterns of variation and invariance to highlight the critical aspects of a phenomena. The argument is that:

By consciously varying certain critical aspects of the phenomenon in question while keeping other aspects invariant, a space of variation is created that can bring the learner’s focal awareness to bear upon the critical aspects, which makes it possible for the learner to experience the object of learning. (Pang and Marton, 2005, p. 164)

There is evidence to suggest that the patterns of variation/invariance necessary to learn a specific object of learning is dependent upon students' prior learning and experience. Rather than putting the focus on something about a student that cannot be changed, such as their cognitive ability, Lo and Marton (2012) show that through the variation theory lens students fail to learn because either they have not been able to focus on the critical aspects of a phenomena, or they have not been able to focus on all of them simultaneously and understand how they are interrelated.

I suggested above that variation theory might be productive in science because of the complexity of science objects of learning and the potential of the theory to reduce complexity (Nilsson, 2014). Fraser et al. (2006), in the context of university student learning about distillation, found that changing two variables in the learning situation was preferable to changing six. Variation theory can be credited here for offering a means of reducing the complexity.

Patterns of variation create a space of variation for the learner. Pang and Lo (2012) show that the spaces of variation that is created in lessons for learners may not be what the teacher intended. They used variation theory to 'reverse engineer' an enacted teaching sequence to allow them to explain some of the problems students had demonstrated in a post-test. They took an enacted sequence and identified what had been varied and identified what it was that students might have learned.

The particular sequence Pang and Lo (2012) analysed was from a lesson about fractions. In the lesson the teacher counts out 10 cubes and puts them in a bag and then takes out different numbers of cubes. Pang and Lo (2012) explain that the teacher intended for students to experience that if a whole object is divided into 10 equal parts then each part is equal regardless of how many parts are selected. However, the enacted pattern of variation in the lesson suggests that students learned that a fraction depend on the numerator, that is how many cubes where taken out of a bag each time. This is an example of how variation theory offers a means of scrutinising teaching and learning episodes by looking at patterns of variation. These patterns of variation offer the teacher an insight into what a learner may have experienced and what they have experience may not be what the teacher intended. It is reported that some teachers are surprised at differences between what they offered and what children in their lessons experienced (Ljung-Djärf et al., 2014).

A further important part of variation theory is that students need to experience simultaneous variation in the critical aspects of the object of learning (Pang and Marton, 2005). Pang and Marton (2005) argue that offering students' experience of simultaneous variation in the critical aspects will widen the space of variation and result in more opportunities to experience the critical features and improve understanding. Unless a learner experiences simultaneous variation in the critical aspects they may think, going back to the example above, that all red objects are apples. Unless they experience a red apple as both a colour and a fruit they will not have experienced both of these critical features simultaneously.

Pang (2010) deals with one example of an object of learning that is different from other reported studies, 'financial literacy'. This object of learning is operationalised by identifying concepts necessary to make decisions about financial matters, and the relationships between these concepts. Financial literacy is described as 'domain-specific generic capacity'. This finding suggests that more generic scientific capacities could be approached using variation theory.

4.4 Conclusions

In summary, each phenomena has a variety of aspects and features. Which of these aspects and features that are critical will depend upon the learner. Establishing what is critical is an empirical problem and can be found by use of pre- and post- tests, student interview and teacher experience.

In order for learners to learn something they need to have experienced variation. What comes into their focal awareness will depend upon a pattern of variation, and variation theory offers teachers a tool for working out the best pattern of variation for their group of students. Ingerman et al. (2009) point to two stages of learning from variation theory, firstly learners need to discerning variation in aspects and secondly deriving meaning from the experience of the variation. Thus the presence of appropriate variation does not guarantee discernment of critical features but it is a necessary condition (Marton and Pang, 2006).

5 Variation theory in learning study

Variation plays multiple roles in a learning study and in this section I will examine these sources of variation in more detail. Variation is present in three different ways (Cheng, 2014; Elliott, 2012; Ko, 2012):

- V1 is the variation in students' ways of understanding a phenomena
- V2 is the variation in teachers' experience and knowledge, including their understandings of student learning
- V3 is when variation is used a principle to guide planning and teaching.

Within Figure 1 below the different phases of a learning study can be seen and an indication is given in each stage about what sources of variation are drawn upon. For example, in the early stages of a learning study teachers work together to select a suitable topic, and associated object of learning, and an important source of information to help at this stage is range of experience and knowledge they bring. Different teachers will have different insights and will be able to contribute different insights into the problems that students have with a particular object of learning, and ways to overcome these problems. In the absence of V2 trainee teachers could draw upon literature about student learning difficulties.

It can be seen from the diagram that the second stage is to identify a tentative object of learning. The object of learning is only confirmed after pupils' difficulties with learning have been diagnosed. I am re-emphasising here that the object of learning (and associated critical features) are empirically determined and are particular to a group of students. As mentioned above in learning study, variation in students' initial understanding of phenomena (V1) are seen as a source of helpful information (Pang and Lo, 2012).

The next stage is to plan the research lesson and as well as drawing upon the range of teachers' experience, the group of teachers also uses variation to inform the teaching strategy. More details about the use of patterns of variation are given in the next section of this report. The main principle, however, is that students need to experience difference against a background of sameness in order to discern the object of learning. The lesson plan is then taught by one member of the group and observed by others. Then V1, V2 and V3 are drawn upon in the process of evaluating and reviewing

the lesson for the next time it is taught (this particular model draws upon the Japanese lesson study cycle approach but, as described above, other versions of learning study are possible which are based on design experiments with an experimental and control group).

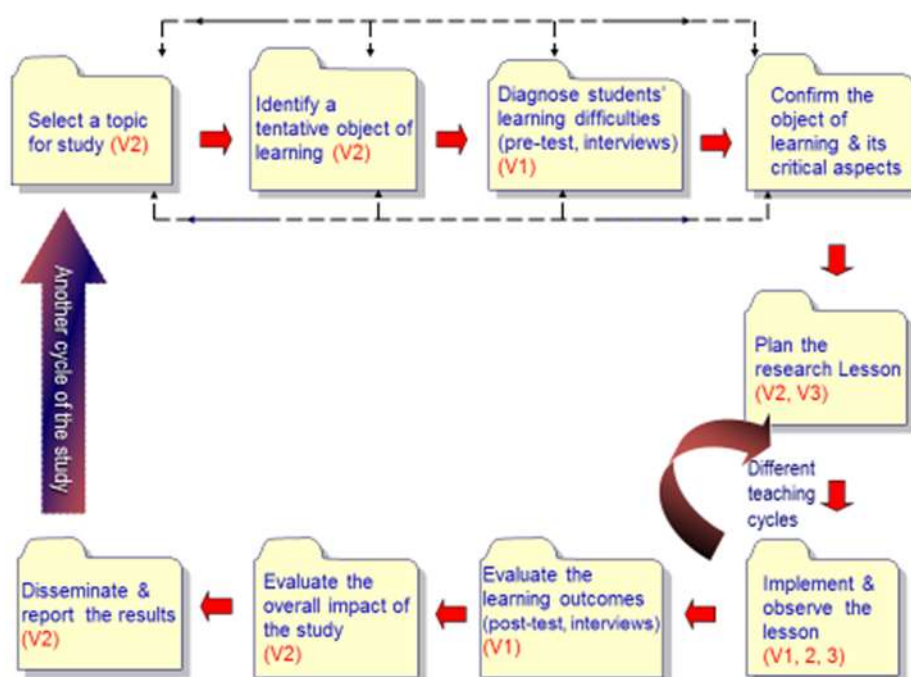


Figure 1: Sources of variation in learning study (Cheng, 2014)

In the later stages of an individual learning study it can be seen that there is an opportunity to evaluate both student and teacher learning through the study. In other words the idea is to find differences between V1 and V2 at the start, and at the end of the study. There are different approaches identified in the literature to capturing any differences.

For V1, in many studies details of the questions asked to students in questionnaires and in interviews are not reported. Ljung-Dj  rf et al. (2014), however, described and justified their individual interview questions. Nilsson (2014) included the questions asked about ions but does not explain why these particular questions were asked. Lo (2009) report identifying three different students (high, average, low performers) for interview and this seems a sensible approach, one in line with lesson study literature (DCFS, 2008). Runesson (2013) reports an interpretative approach used by teachers when looking at diagnostic pre-tests. For them, the scores in the test are not the main point of interest. This view of data gained from questionnaires and interviews is more compatible with assessment of learning literature (Black and Wiliam, ????) and more in line with University of Birmingham philosophy than trying to make sense of quantitative data gained from small scale test data using descriptive statistical methods.

Furthermore, Tan and Nashon (2013) reported how a teacher, who was part of the collaborative learning study group, collected data about students' learning and teacher pedagogy *during* the research lesson. Again this is in line with assessment for learning literature and something that would be compatible with University of Birmingham current practice.

When identifying which qualitatively different way of experiencing a phenomena an individual student has demonstrated, Pang and Marton (2005) used the highest (rather than 'best fit' or other method) that that student had demonstrated. A further useful observation from the literature is that Pang (2010) adopted a new approach for analysis which, influenced by phenomenography, identified the number of critical aspects of a phenomena considered simultaneously, and also considered the meaning of the phenomena.

Variations in V2, that is variation in teacher knowledge and attitudes have been captured using phenomenological inspired approaches which identify qualitatively different ways of understanding teaching and learning. Other approaches have also been used. Tan (2014), for example, used a conceptual change approach while Nilsson (2014) used a framework based on Pedagogical Content Knowledge (PCK).

The range of data sources that are collected and analysed in learning study (Tan, 2014) have some of the characteristics of a case study approach which draw on a similarly wide range of data.

6 Patterns of variation in teaching – further explanation

As I have tried to demonstrate above, variation theory points to the need for teachers to use patterns of variation in their teaching. By patterns of variation I mean that the critical features that have been identified in the pre-tests and pre-teaching interviews will be systematically varied such that particular features come into students' focal awareness. In other words patterns of variation can be used to help the learner discern the critical features of the object of learning.

Marton and Pang (2006, p. 195) insist that:

The focus on what varies and what is invariant derives from the specific framework the teachers are making use of; and the choice of other factors, such as whole class teaching, group work, and forms of representation, and the use of textual or electronic resources is subordinate to the teachers' design of the patterns of variation and invariance.

Marton and colleagues identify four patterns of variation; they are contrast; separation; fusion and generalisation (Marton and Tsui, 2004; Marton and Pang, 2006; Marton and Tsui, 2004). I will now take each of these in turn.

Contrast is where the learner experiences variation such that a particular value or feature is brought to their attention. For example

to experience what "black" is, the learner must experience other colours such as red or white. Only after having experienced other values (red, white, etc.) of the aspect (colour) can the learner discern the specific colour of black (Guo and Pang, 2011, p. ??)

Separation involves the learner focusing on one aspect of a situation and this is achieved by varying only that one aspect of the object of learning and keeping other aspects invariant. The example given by Guo and Pang (2011) is that colour can be separated from other aspects by keeping other aspects such as size, shape and height invariant. A particular example of this, to follow on from the example I gave earlier would be to present the learner with different coloured apples, all of the

same size and shape. The goal is for the learner to separate one aspect from other aspects (Guo et al., 2012).

Generalisation is when a learner is able to apply what they have learned (or discerned) to a range of contexts. The learner needs to be able to separate the critical aspects from that which is irrelevant. For example when a child was shown a red apple, and the teacher wished to teach the colour red, that the child was shown an apple is irrelevant because its intended focus is on the colour of the object. Carstensen and Bernard (2007a, p. 5) give the example that “in order to understand what “three” is, we must also experience varying appearances of “three””

Fusion is where the whole-part relationship between critical aspects is taken into account. Students would, therefore, need to experience all critical aspects at the same time. An example of this is in fractions teaching students would need to experience both numerator and denominator at the same time (Lam, 2012). During fusion a learner will experience individual parts of a phenomena at the same time as the whole of the phenomena. Thus they would be able to experience the apple described as an apple, red and a piece of fruit simultaneously.

There has been some research done about the order in which these four patterns of variation should be used. Lo and Marton (2012) suggest that the pattern should start with fusion. This, I think is so that the learner experiences the phenomena as a whole and in context. Following experiencing the object as a whole the teacher would then introduce contrast, then generalisation and finally fusion as the learner now should have experienced the critical aspects such that they are able to discern them.

Examples of the four patterns of variation are emerging in the published literature. I will now give two science specific examples from literature. In their study about organic decomposition, Ljung-Djårf et al. (2014) introduced contrast by showing students samples of fresh fruit/vegetables and these were contrasted with the same samples of mouldy fruit/vegetables.

Lam (2012) used patterns of variation to teach about rates of reaction. She contrasted fast and slow reactions, for example iron and potassium in water. The purpose of this contrast was to introduce the idea of reaction rate, or to put it another way a critical aspect. She then used separation by showing three different experimental set-ups which can be used to collect evidence about rates of reaction but kept the chemical reaction invariant. The point of using separation here was to teach students that the experimental set-up did not affect the rate of reaction. Finally Lam (2012) used fusion by varying concentration and volume simultaneously so that students can gain understanding of the whole-part relationship between them.

Although the term ‘separation’ is not part of the description of the study about light by Lo et al. (2006), patterns of variation were deliberately used. Students were shown a prism, soap bubbles and water droplets so they experience different tools to split white light. They were, thus, exposed to a critical aspect, that there are tools which split white light into a spectrum. Thus the varying aspect is the type of tool, but the role of the tool (to split white light into component parts) remains invariant.

Some work has been done about the times in which phenomena have been encountered and this seems to indicate that students do not need to experience critical aspects of a phenomena at the same chronological time. In particular Bernard (2010, p. ??) describes:

...diachronic (experiencing, at the same time, instances that we have encountered at different points in time) or synchronic (experiencing different co-existing aspects of the same thing at the same time).

However, for the purposes here, and at the early stages of using variation theory that consideration is only given to aspects of a phenomena that are experienced during a lesson. Nilsson (2014) also writes about variation being achieved by contrasting new learning with relevant prior learning. Again this may be a useful consideration once basic variation theory has been mastered.

Based on their learning study, Ingerman et al. (2009) suggest that it may take time for student to experience variation and as a consequence for them to become aware of critical features:

The current descriptions of 'variation theory' to be found in the student learning literature are principally embedded in teacher action. This teacher action can be seen to carry the implication of a learning spontaneity for students who, through variation, discern critical features of an object of learning. Our data, however, suggests that there is far more likely to be a temporal than an instantaneous dynamic..." (Ingerman et al., 2009, p. 291)

From this quote two important points emerge. The first is that we need to be cautious about linking too closely teacher action and student learning. Teachers' pedagogical acts are not directly coupled to student learning. The second point is that there may be coupling between pedagogical acts and student learning but it may not be instantaneous.

In the discussion in this section I have tried to show how variation theory offers a means of planning for the teaching of the object of learning, but without specifying the specific teaching approaches or activities. Thus it offers a bridge between what a teacher intends for students to learn and the activities and strategies that a teacher uses to help them to experience the critical aspects the object of learning.

7 Learning studies reported in literature

Learning studies have been undertaken in a range of different context. These include pre-school (Ljung-Djärf et al., 2014); primary school (Runesson, 2013; Holmqvist, 2011); and secondary school (Nilsson, 2014; Pang, 2010; Pang and Marton, 2005; Pang and Lo, 2012; Tan, 2014 and Tan and Nashon, 2013). They have also been undertaken in the context of teacher education (Davies and Dunnill, 2008, Ko, 2012; Cheng, 2014).

I will list here an indication of the learning studies that have been undertaken. In science subjects studies include Tan (2014) and Tan and Nashon (2013) who examined genetics. In chemistry Nilsson (2014) looked at ions and ion formation; Pang and Lo (2012) looked at rates of chemical reactions; Ljung-Djärf et al. (2014) studied organic decomposition, and Lo and Marton (2012) examined the electrochemical series.

Studies outside of science subjects include Holmqvist et al. (2007) who looked at telling the time, and Pang and Lo (2012) who report a study on fractions. In economics and business Pang (2010) reports on financial literacy. Pang and Marton (2005) report on the market price of commodities. Further studies by Holmqvist et al. (2007) report English as a second language and Swedish as a first language. In her 2011 article, Holmqvist reports a further study on Language lessons (three learning

studies: possessive pronoun; 'to be' in present tense; 'to have'). Ko (2012) report metrical poetry and Lo and Marton (2012) explore Cantonese opera.

8 Other relevant literature which report findings outside of learning studies

In literature there are other science based studies that have been reported that make use of variation theory but not in the context of learning study. These include a chemistry based study where Lam (2012) examines rates of reaction. Furthermore in the context of physics Ingerman et al. (2009) looked at the Bohr's model of the atom. In the context of university level engineering, studies have included the topics of electric circuit theory (Carstensen and Bernhard, 2007a, 2009); mechanics and electric circuit theory (Bernard, 2010) and distillation (Fraser et al., 2006).

Other studies which have make use of variation theory have looked at enhancing creative writing (Runesson and Gustafsson, 2012); Chinese language learning (Chik and Runesson, 2008) and mathematics (Kullberg and Runesson, 2013).

In addition to studies that have made use of variation theory explicitly, there is a substantial body of work reporting phenomenographic studies. I list a small number here to make the point that these offer useful insights into the qualitatively different ways that learners experience phenomena. For example Bowden et al. (1992) identified qualitatively different ways of experiencing displacement, velocity and frame of reference. Swarat et al. (2011) report a typology of 'size and scale' and Paakkari et al. (2011) describe health teachers' conceptions of pupils learning. There is a bibliography of these and many more studies in the appendix to this report.

9 Roles in learning study

Within learning study there are four possible roles. The first role is that of the teacher. In the context of learning study the teacher is also a learner, a learner of their own practice. This learning come through the process of learning study, through reflections on the process and also by being part of collaboration with other teachers. As discussed above teachers in learning study are a source of V2, that is the range of teachers' experience and knowledge about the object of learning and the difficulties that students face when learning it.

A second role is that of the researcher-facilitator. Tan (2014) describes that as a researcher-facilitator she undertook tasks of: coordination of meetings; facilitation of discussions; taking minutes in meetings; being a source of knowledge of variation theory; offering critical insights in evaluation meetings and helping with analysis of test data. Runesson (2013) emphasised that one role of researcher-facilitator is to encourage teachers to justify the decisions they have made and suggest alternatives.

A subset of the role of the teacher is the role of a trainee teacher. As discussed above, trainee teachers share the characteristics of being both teachers and learners. However, a key difference is that trainee teachers do not possess significant amount of knowledge about the object of learning and difficulties that students face when learning it (that is V2). V2 is an important part of learning study and other sources of V2 would need to be identified. This could be from published literature but it may also come from discussions with teachers outside of learning study.

Given that teachers and researcher-facilitators come from somewhat different perspectives it might be expected that they may view the process of learning studies in different ways. An example of this is reported by Tan (2014) who points out that the role of variation theory in learning study may be seen differently by teachers and researcher-facilitators.

School leaders also play an important role in learning study because they will need to support the learning study communities (Tan, 2014). Nilsson (2014) asks how can school culture support teachers as they seek to develop innovative practices through collaboration, thus highlighting the role of school culture.

10 Sharing of findings from learning study

There are potential outcomes from learning studies for both the teachers involved and the students who were in the learning study research lessons. The main outcomes include changes to the attitudes, knowledge and understanding of teachers (I include trainee teachers here). There are also outcomes for students, their knowledge and understanding of the object of learning.

Runesson and Gustaffson (2012, p. 247) make a useful statement about the knowledge product from learning studies:

... the knowledge product of a learning study is a description of the object of learning in terms of those features that were found to be necessary for the students' learning, hence the critical features. In addition to such identified critical features, the knowledge product of a learning study also describes how variation was used as a means of bringing these critical features out in the lesson and making them discernible. In this way, the knowledge product of a learning study is not a lesson plan in the full sense of the word, but more like a lesson design in terms of "the pattern of variance and invariance of the critical features it contains" (Kullberg, 2010, p. 35)

Sharing the knowledge product is an important part of a learning study and the product is potentially very useful to teachers, schools and wider teacher communities. In the Appendices I have included two examples of knowledge products in the form of patterns of variation and invariance. Appendix 2 is reproduced from Pang and Marton (2013). In Appendix 3, Lam (2012) presented her findings in a table with a flow of stages of the lesson with different patterns of separation and fusion. This approach offers a means of sharing the knowledge product in a way that would be readily digestible for busy teachers.

The adoption of a 'tight procedural package' in learning study (Elliot and Ko, 2008, in Lo, 2009) may have resulted in unjustified assumptions about comparability between different studies. Thus studies may not be as comparable as they first appear. However, claims associated with the patterns of variation and invariance, of which there are examples in Appendices 2 and 3, are modest and these patterns can serve as inspiration for teachers as they identify objects of learning, critical features and patterns of variation for their particular classes.

11 Concept maps

Within the University of Birmingham Science ITE courses concept maps are used as part of the medium term lesson planning process. Concept maps are recognised as being helpful for beginning teachers because they help to see the topic in a different way:

Consideration of a teaching topic as depicted by a variety of map structures may help the 'subject-expert novice-teacher' to view the topic through the eyes of the subject-novice (student) and so increase the possibility of developing an effective dialogue between teacher and student. (Kinchin and Alias, 2005, p. 569)

A key question then is how to combine concept maps with the use of variation theory.

Davies and Dunnill (2008) distinguish between concepts, which are either understood or not, and conceptions, which can be replaced with one that is more complex. The latter perspective is one found within phenomenography. Conceptions of a phenomena can be shown in a concept map with different concept/ link arrangements associated with different conceptions.

"Model of complex concepts" which highlights that knowledge is made up of interrelated concepts (Carstensen and Bernard, 2007b, 2009; Bernard, 2010). This has similarities with the 'learning outcome circle' suggested by Davies and Dunnill (2008) where a range of concepts associated with the object of learning are placed in a circular configuration. Lines are then used to highlight relationships between these concepts. Different lines joining concepts can thus represent different conceptions associated with the object of learning.

Concept maps have the potential to help teachers to identify the objects of learning in a learning study and also to identify the critical features. Critical features might be associated with definitions of concepts or relationships between concepts. Thus concept maps offer the potential to be a step toward identifying critical features of an object of learning.

12 The potential of learning study to be used at University of Birmingham

Tan (2014) reports some of the challenges associated with implementing learning studies. These include the feasibility and sustainability of learning studies; tensions between teachers and researchers; roles of leaders and schools in supporting learning study communities. Furthermore, Elliott (2012), in his review of the VITAL project in Hong Kong, reports that some school Principals saw the benefits of condensed learning studies but seemed to suggest these may best serve as a 'top up' from a previous full learning study. Full learning studies are demanding in terms of teacher time and commitment. An example of a condensed learning study approach is shown in the Case Study box below.

Ko (2012) describes how in a module where trainee teachers completed a learning study the tutor assigned a common learning topic with the view to reducing the time spent on selecting a topic and also to allow for students to be able share ideas about the topic. While there are benefits to this approach it also serves as a challenge to the ownership of the study.

Ko (2012) reports that the implementation of a module in which trainee teachers undertake learning studies was challenging to organise, to liaise with schools and required significant time and effort. Furthermore, Ko (2012) indicates that tutor support is a determinant of the quality of the work done by trainee teachers. As mentioned above, introducing trainee teachers to learning study through a

standalone module suggests that variation theory and collaborative practices are not a necessary part of teaching and learning, and trainees might not integrate the approaches into their everyday work.

Teachers have expressed concerns about the practicalities associated with undertaking a learning study (Tan, 2014) and Tan (2014) points out the need to take these concerns seriously, but at the same time being in mind that challenging them is important. Thus any implementation of learning study at the University of Birmingham would need to consider the concerns of those in schools seriously.

Case Study: A condensed learning study approach

A condensed learning study has been done in Hong Kong where the total time allocated is 12 hours. In this Case Study I report my understanding of the approach.

The start of the learning study is a 6 hour workshop where teachers are introduced to the principles of learning study and variation theory. A lesson is then planned collaboratively and taught by one of the members of the group, and observed by others. At the end of this lesson three students identified as high, middle and low achieving are selected for interview.

During the interview the researcher-facilitators ask questions to the three students about their understanding of the object of learning. The teachers involved in the study sit behind the pupils and listen to the questioning and the answers offered to by the students.

Following the group interview teachers plan a revised lesson on the same topic but to a different class. The teachers and researcher-facilitator have new insights about the object of learning from their experiences in the first lesson. Following the second observation a further group interview is conducted and it is possible to compare the acquisition of the object of learning in the first lesson with the second lesson.

At the heart of learning study there are four core principles. Firstly that there is an opportunity for teachers to collaborate in small groups with a clear focus on planning, reviewing and improving a research lesson with a particular focus. Secondly learning study makes use of variation theory as a tool for rigorous and structured analysis of lesson content. Variation theory is used to plan, teach and review lessons, and to evaluate the success of lesson from the perspective of teachers and students.

The third core principle within learning study there is an opportunity to examine the success of the research lesson by comparing to other lessons. There are two ways this could take place. One way is when an 'experimental' group, where a learning study approach is adopted, is compared with a 'control' group. A further way is to comparing learning study lessons in a developmental cycle where the research lesson is developed and improved by drawing on experience from a previous lesson. Finally, the fourth core principle is that students are different and it is important, and necessary, to plan lessons based on information gained from specific groups of learners. In learning study this information is called V1 and is gained through interviews and testing.

If learning study is operationalised such that it includes these four core principles, then I think there are three possible ways that the approach could be adopted at the University of Birmingham. These three approaches might be called integrative; periodic or wholesale. Table 1 below gives a summary of the four core principles and the three possible ways learning study could be adopted at the University of Birmingham. We do not know from learning study research whether learning study is more than the sum of its component parts. However, there is enough evidence to support the inclusion of these four core principles in a programme.

In each of the three models for adopting learning study membership of the learning study group would include a University tutor as researcher-facilitate, as described above. This is a necessary role as mentors, teachers and trainee teachers would need clear input in variation theory and the procedure of learning study. A further point to note is that in each of the three models the learning study is located *in the school context*.

In the integrative approach elements of learning study would be integrated into existing programmes in a measured and gradual way. One example of this might be that in lesson planning sessions during the PgDipEd and PGCE (SD), variation theory would be introduced as an analytical framework which would sit alongside existing lesson planning and evaluating frameworks. The addition of a further layer could benefit students as it would give them further tools to improve their lessons both during their ITE year and beyond.

In the periodic approach one or more learning studies would be included in the PgDipEd or PGCE training year. These would be stand-alone activities where a learning study group come together for the purpose of the learning study. The group may be within the same school or across schools.

Description		Integrative	Periodic	Wholesale
		The three core elements of learning study are integrated into existing programmes without substantial structural changes to programmes.	Within a training year (and perhaps beyond) learning study/ies are included as part of the annual cycle. Perhaps one full scale study is conducted in the second half of the training year.	The model of Learning Study is used as a means of structuring the entire teacher education programme, both mainstream and School Direct.
Learning Study	Small group of teachers collaborating	Opportunities for mentors, teachers and trainee teachers working together exist while on school placement. Guidance would need to be given to identify opportunities.	Small groups are set up specifically for the purpose of conducting learning studies. They may be within schools or across schools. Times in the year would need to set aside in a calendar.	Small groups of mentors and trainee teachers, supported by researcher-facilitators, would need to be set up, and perhaps there would need to be different groups for different purposes.
	Use of variation theory to plan, teach and evaluate lessons.	Variation theory is integrated into existing lesson planning approaches on a gradual and developmental way during the training year.	Learning study could be adopted following the relatively 'tight procedural package' found in the literature described in this report (and shown in Figure 1). However, decisions would need to be made about resources. Challenges would exist around mentor availability; school 'buy in'; and university tutor workload.	Learning study addresses some of what new teachers need to learn. However, there are many elements of teacher education it does not address, such as Whole School Issues and behaviour management.
	Comparison of lessons to give indication of success of approach	Teaching the same lesson content twice (or finding a control group) is challenging to organise in a structure way, but in larger schools it may be possible. It may be possible during Serial Placements.		
	Information from specific groups of learners – V1	Existing approaches draw inspiration from Assessment for Learning and require a two way dialogue between trainee teacher and student learners. Further insights could be gained from learning study approaches.		

Table 1: Summary of how learning study could be adopted at the University of Birmingham

13 Conclusion

On balance the complete replacement of existing structures, according to the Wholesale approach described above, does not seem something that would be desirable as there is too much to risk in such an approach. An approach where learning study is used periodically also has drawback. It is not established into lesson planning routines and the one off approach suggests that it is not essential as part of teaching. The lived out implication of an intervention is that it is not an essential part of teaching and is optional.

The integrative approach, at this stage offers the most potential at the University of Birmingham, where elements of the learning study approach are integrated in a planned and gradual way, perhaps starting with science. The integrative approach offers two main benefits. Firstly that the form of teacher training is based within the school context. Secondly that there is a clear and justifiable role for the researcher-facilitator, which is beyond the school context.

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Appendices

Appendix 1: Questions asked to teachers during planning meeting for learning study

- What are the important points of teaching this topic?
- What common errors and confusions do students have when learning this topic?
- How do students make sense of the topic?
- How did you handle the same object of learning in the past?
- What do you think are the critical aspects of understanding this topic?
- What were the difficult points of teaching this topic in the past?
- How could we make students develop an economic way of understanding this phenomenon?

Appendix 2: Example of how to present the patterns of variation and invariance (Pang and Marton, 2013)

<u>Pattern consistent with the conjecture</u>					<u>Pattern consistent with the conjecture</u>				
Demand	Supply	Magnitude of Change in Demand	Magnitude of Change in Supply	Commodity	Demand	Supply	Magnitude of Change in Demand	Magnitude of Change in Supply	Commodity
v	i	v	i	i	v	v	v	v	i
i	v	i	v	i	v	v	v	v	i
v	v	v	v	i	v	v	v	v	i

Fig. 3 Patterns of variation and invariance compared in the studies reported in this paper; *v* = variant, *i* = invariant

Appendix 3: Pattern of Variation and Invariance used in a series of chemistry lessons (Lam, 2012)

Table 7.1 Patterns of variation and invariance used in the research lessons

Introduction (01.1)	Object of learning 1	Type of chemical reaction	Reactivity of metal	Reagent used (water)	Laboratory set-up	What is discerned
	Fair test concept	Invariant	Varies	Invariant	Invariant	Reactivity of metal affects the rate
	Object of learning 1	Type of chemical reaction	Reactivity of metal	Concentration of acid	Laboratory set-up	What is discerned
	Design of laboratory set-up	Invariant	Invariant	Invariant	Varies	Different set-ups are required to measure different physical parameters, depending on the characteristics of the reaction
Experimentation (01.2)	Object of learning 2	Chemical reaction	Laboratory set-up	Factor assigned for investigation (e.g. strength)	Factors not under investigation (e.g. volume, basicity)	What is discerned
	Factors affecting initial rate and amount of products	Invariant	Invariant	Varies	Invariant	Factor under investigation is/ is not a factor
Debriefing (01.3)	patterns of variation	Debriefing sequence 1 "rate-product-rate-product" in class 4C		patterns of variation	Debriefing sequence 2 "rate-rate-product-product" in class 4D	
	separate each single factor, flag the 2 aspects "rate" and "product", then flag all the factors without separating the aspects	strength ↔ rate		separate the aspects "rate" and "product", for each aspect, separate each single factor, and then flag all the factors while keeping the aspects apart	strength ↔ rate	
		strength ↔ product			basicity ↔ rate	
		basicity ↔ rate			concentration ↔ rate	
		basicity ↔ product			volume ↔ rate	
		concentration ↔ rate			same ratio ↔ rate	
		concentration ↔ product			different mole ↔ r	
		volume ↔ rate			strength ↔ product	
		volume ↔ product			basicity ↔ product	
		same mole ↔ rate			concentration ↔ p	
		same mole ↔ product			volume ↔ product	
		different mole ↔ rate			same ratio ↔ prod	
		different mole ↔ product			different mole ↔ p	

