The Use of Drama in A Level Chemistry: A study into the effects of simulation-role-play on the quality of, and student attitudes towards, learning of organic reaction mechanisms.

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The candidate confirms that the work submitted is her own and that appropriate credit has been given where reference has been made to the work of others.

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Abstract

This study looks at the use of simulation-role-play, a subset of drama, as a pedagogical tool to prepare A Level Chemistry students to answer examination questions relating to organic reaction mechanisms.

The mixed methods approach involved a quasi-experimental intervention in schools and further education colleges with two parallel A Level Chemistry classes, one using practice examination-style questions, and the other using simulation-role-play.

Analysis of post-intervention assessment items, in the form of A Level Chemistry examination questions, revealed no statistically significant differences between the scores of the two groups, irrespective of whether the drama group had used a pre-prepared script or written their own. Analysis of responses to a diagnostic question found a statistically significant difference in favour of the drama group. It is proposed that the use of simulation-role-play contributed to deep learning in a way that traditional teaching methods did not.

Analysis of attitudes gained from group interview transcripts, using grounded theory, showed a mixed picture. Some students felt that the use of simulation-role-play as a pedagogy had helped them recall the chemistry, while others felt it was confusing. Some students articulated they felt the use of simulation-role-play allowed them to obtain an understanding of the chemistry being studied. Some students perceived that the use of simulation-role-play in isolation was not an effective pedagogy to prepare students for completing examination questions. This was *not* borne out by the marks obtained in the post intervention examination questions, where there was no statistically significant difference in scores between the groups. Students also reported that they felt it is not always necessary to understand the relevant chemistry to gain marks in an examination question.

It is proposed that simulation-role-play, contributes to the development of strong mental models in two ways. Firstly, it provides an embodied, macro experience allowing students to access macroscopic,

descriptive level thinking. Secondly sub microscopic explanatory level thinking is accessed through students being able to simultaneously experience real and imagined worlds and make sense of both at this interface. The mental models generated through the use of practice examination-style questions incorporate aspects of the sub-micro and symbolic dimension but not the macro dimension, therefore removing the opportunity for students to transform meaning at the interface of the macro and sub-micro worlds. The stronger mental models generated through the use of simulation-role-play, and generation of associated deep learning needed to answer this question, could account for the difference in responses to the diagnostic question, with a statistically significant difference in favour of the drama group.

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Introduction

1.1 Setting the scene

That effective teaching of chemistry is required in order to nurture competent and creative chemists was made clear to me during both my early career as a research and development chemist in the area of industrial organic chemistry and also through my subsequent work teaching GCSE and A Level Chemistry in secondary schools and a college of further education. During my time as a teacher, I developed, and implemented in the classroom, a number of pedagogical practices that involved the use of drama in the science classroom at KS3 and KS4. As a teacher, when I reflected on my classroom practice, I would often find myself thinking critically about the effectiveness of various aspects of the teaching methods I employed. After working in a range of schools and colleges for twelve years, I left to assume two new roles: director of Salters' A Level Chemistry, and course leader for initial teacher training in the sciences at the University of York.

It was whilst working at the University of York that I started to encourage trainee science teachers to use drama as a classroom pedagogy. At times, I was challenged on my advocating of drama's utility in the science classroom and, in defending my position, I realised that I was making my argument on the basis of 'gut feeling' as well as my own teaching experiences. This insight led me to further, and more critically, question whether drama, as a classroom pedagogy, actually is effective in promoting learning within science education. Chemistry has always been my subject of choice and is traditionally viewed as being a 'difficult' subject. In spite of this perceived difficulty, or maybe even because of it, some of my most rewarding teaching experiences have occurred while working with students studying A Level Chemistry (age 16-18). It was due to the difficult nature of the subject matter and the experiences that I had previously had when teaching it that my academic curiosity was particularly piqued. Having debated it with others on various occasions, I became interested in finding out whether there was evidence to show that the use of drama, in the context of A Level Chemistry, is an effective pedagogical tool to assist in teaching and learning. I wanted, ultimately, to place myself in a stronger position to be able to help teachers to make rational, informed decisions about the pedagogical choices they make in their classrooms. The answer to these questions and aspirations suggested itself in the form of a PhD study involving systematic research. This thesis is the result of that decision and it both presents the findings of the research I conducted in schools as well as making a new contribution to existing scholarship concerning the use of drama in science education.

The existing literature reveals, when surveyed, that there have been a not insignificant number of studies carried out into the use of drama in science education. Notably, the majority of those studies have concerned themselves primarily with younger children in early years of schooling; there has been markedly less research carried out with a focus on school students over the age of 16. Furthermore, many of the studies reported in the existing literature are concerned in the first instance with investigating student perceptions and enjoyment of drama when used in science education, as opposed to analysing the quality of students' learning of science. In this context, the nature and focus of the act of learning in science is subdivided into two main categories: first, how science works (working scientifically); second, scientific concepts. The latter category, the learning of scientific concepts, has been the subject of less research, and it is the area that this thesis is most interested in. In particular, it is the issues that surround the use of simulation-role-play, in which students act out the roles of entities involved in chemical reactions, as a classroom pedagogy for the teaching of chemical concepts to students aged 16-18 that are central to this study. The reason for that is not only my own personal interest but also the fact that there is, to date, no scholarly literature that addresses this area of educational theory and practice.

To address this gap in the literature, I chose in this study to focus on the teaching and learning of one particular area of chemistry: organic reaction mechanisms. As a topic within the science curriculum, organic reaction mechanisms are first introduced as part of the A Level Chemistry content, and so they are not covered by GCSE courses (taken by students typically aged 14-16). This quality was deemed to make it an ideal topic for use in this study, as students having prior learning in this area of chemistry would be highly unlikely, and so there was a minimised chance of the reliability of the results being adversely affected. Moreover, referring to examination board documents and the literature that does exist, it became apparent that the topic of organic reaction mechanisms was one that commonly presents students with the kind of conceptual challenge that I was interested in exploring.

In light of all of the factors mentioned so far, this study was designed to assess the effectiveness of the use of simulation-role-play for the teaching and learning of organic reaction mechanisms. The conclusions that this thesis ultimately draws in that regard are based upon the results of an intervention: I worked with schools and further education colleges that ran two parallel A Level Chemistry classes. To generate the data for analysis that I required, I taught exactly the same curriculum content to both sets of classes in the participating schools, but did so in two different ways: one group was taught using traditional methods with practice examination-style questions whilst the other group was taught using simulation-role-play. Having taught the content in that manner, I was then able to utilise authentic A Level questions in order to statistically ascertain whether or not there were any significant differences between the performances of the two groups.

In addition to the teaching and analysis of responses to A Level examination questions, I also conducted a series of group interviews in order to find out more about the students' attitudes towards the lessons they had experienced. More than simply whether or not they had enjoyed it, I was particularly interested to discover whether or not the students perceived the lesson to have helped them to understand and remember the relevant chemistry and to answer examination questions and, why they thought this.

Whilst this thesis is set within a broad background it sets out to address a specific issue and to provide an answer to one, main, research question: does the use of simulation-role-play in the teaching of organic reaction mechanisms in A Level chemistry impact upon student learning?

To fully address that research question, four more specific questions were devised in order to engage with the key aspects and to focus the analysis. These questions are:

i. Do students' marks in A Level examination questions on organic reaction mechanisms differ, in a statistically significant manner, depending on whether they have been taught using simulation-role-play or practice examination-style questions?
ii. How do students perceive the use of simulation-role-play in their recall of organic reaction mechanisms?

iii. How do students perceive the use of simulation-role-play in their understanding of organic reaction mechanisms?

iv. How do students perceive the use of simulation-role-play in preparing them for answering examination questions relating to organic reaction mechanisms?

In order to address these questions over the course of this study a range of quantitative and qualitative data were gathered, analysed and the results reviewed, leading to conclusions being drawn and recommendations made. The following section provides an overview of these stages and of the structure of the thesis as a whole.

1.2 Outline of the thesis

This thesis consists of five chapters, the first of which is this introduction. Chapter 2 presents a review of the existing literature that addresses the question as to why science, and chemistry in particular, is considered to be difficult for students to understand. Levels of grade severity of external awards such as GCSE and A level when compared with other subjects in the curriculum (Alton and Pearson,1996, cited in Coe et al., 2008, p.66) indicate that chemistry is one of the most challenging subjects. The issues explored in considering why this might be the case include the demands made in scientific thinking when moving from the macro to sub-micro and symbolic representations of a chemical concept (Johnstone, 2010) This theoretical framework provides a lens through which other aspects can be viewed. These other aspects include relevance of chemistry to the real world (Driver and Bell,1986), the challenges associated with scientific language (Wellington and Osbourne, 2010), and another area that often receives critical attention in the literature is that of the role of social interaction in the construction of meaning in science education (Tobin and Tippins, 1993). In this context, the uses of vernacular language in learning and the challenges of making sense of scientific terminology and language are reviewed.

The challenges for students regarding organic reaction mechanisms, as a component of the A Level Chemistry specification, are reviewed (O'Dwyer and Childs, 2011). There has been research demonstrating, for example, that students and undergraduates often do not appreciate that the curly arrows in a mechanism represent the movement of electrons and fail to fully understand the significance of this (Bhattacharyya and Bodner, 2005). Undergraduates and students who are successful in this aspect of chemistry are typically able to view mechanisms as a series of linked steps, with the endpoint of the movement of an electron leading to logical implications for the next electron movement. This stands in stark contrast to the retro-fit approach adopted by many students, wherein they first write out the structure of the product of a reaction and then work backwards to make arrows fit; it also differs from the ‘just learn’ approach, wherein a student simply seeks to memorise each reaction (Grove, Cooper and Rush, 2012).

Chapter 2 examines the position of drama within the curriculum, and this is described alongside an account of the changes to the perception of that role as they occurred over the course of the twentieth and twenty-first centuries. The use of drama within science education is then reviewed in more detail, starting with a consideration of the early work of Finlay-Johnson (1911) and then moving forward in time towards more recent studies, such as that by Hendrix, Eick and Shannon (2012), that have aimed to quantify the impact of drama on science learning. In line with the differentiation between the two different aspects of scientific learning mentioned in Section 1.1, Chapter 2 also makes a distinction between the use of drama to teach, on the one hand, understanding of the nature, processes and methods of science and, on the other hand, specific scientific concepts. Additionally, the chapter includes a review of the different manifestations of drama in the science classroom, including descriptions of work utilising phenomena based role-play, termed by Aubusson et al. (1997) as simulation-role-play. Here students can act the roles of entities in chemical reactions and provides a rationale for the type of drama utilised in this study.

The final sections of the literature review move on to further explore and define what learning is; in doing so, the role of embodied learning in bringing about deep learning is also considered in light of work by Alibali and Nathan (2012) and, in particular, how this deep learning is resultant of the generation of strong mental models (Glenberg, 1999). Concluding the review of the literature, an important link is identified between embodied learning and drama; this link is then positioned as one of the theoretical bases supporting the case to be made for the use of simulation-role-play in science education.

The methodological approach taken by the study is set out in Chapter 3, and the research design is both justified and described. It is explained that a mixed methods approach was adopted in order to generate both quantitative and qualitative data in response to the research questions. A quasi-experimental intervention, followed by the students' completion of post-intervention assessment items, in the form of A Level Chemistry examination questions, generated quantitative data that it was then possible to statistically analyse. The results of that analysis could then be used as evidence when answering the question as to whether simulation-role-play was a suitable classroom pedagogy for the teaching and learning of organic reaction mechanisms at A Level. Chapter 3 also describes the format and design of the questionnaires and follow up group interviews that were used in the study, and the issues of reliability and validity relating to each aspect of the design are, accordingly, also considered. In particular, attention is paid to the manner in which the format of the group interviews were decided upon so as to ensure that they yielded qualitative data that would allow suitable analysis of student perceptions regarding the use of simulation-role-play to help them in recalling and understanding the chemistry content, and also in answering examination questions. Chapter 3 also outlines the approach that was taken in performing the statistical analysis of the quantitative data collected and the analysis of interview transcripts using grounded theory. The ethical considerations of the study are also detailed.

Chapter 4 presents the data analysis; it gives details of the statistical analysis of all the quantitative data as well as the analysis of the qualitative data generated by the group interviews. It is shown that, across the three phases of the study, statistical analysis of the data revealed no statistically significant differences to exist between the scores of the two experimental groups for any of the post-intervention assessment items that were based on examination questions. The results included testing for differences in gender, predicted A Level grade, the number of STEM subjects being studied, and classroom pedagogies experienced in chemistry lessons prior to the study. There was, however, a statistically significant difference between the examination-style question group and the drama group in terms of their responses to the diagnostic question, in favour of the latter.

Using analysis of transcripts from the group interviews, conducted with samples of students from the drama group, it is shown in Chapter 4 that the analysis of the transcripts revealed a complex mixture of responses: some of those students involved reported that they felt that simulation-role-play was an effective classroom pedagogy for teaching and learning this topic whilst others claimed the opposite. In terms of questionnaire responses in Phase 1 of the study, analysis of these found a statistically significant difference between the two groups in regard to their views on the use of practice examination-style questions: to a greater degree than their peers in the drama group, students in the examination-style question group considered that pedagogy to be better for both remembering and understanding the new chemistry. Despite the students' perceptions, there were no statistically significant differences between their test scores in Phase 1. In Phase 2 there were no statistically significant differences between the two groups' responses to the same questions, which was more in accordance with the absence, again, of any statistically significant difference between the scores obtained in response to the assessment items based on examination questions. In both phases of the study the questionnaire responses indicated, at a statistically significant level, that the students in the examination-style question group perceived their pedagogy to have prepared them better for answering examination questions than did their peers in the drama group. Analysis of responses to the diagnostic question in Phase 3 of the study also showed, at a statistically significant level, that students in the drama group had performed better than had their peers in the examination-style question group.

In the final chapter, the implications of the findings that have been presented are discussed. Chapter 5 contends that the quantitative data indicates that whilst simulation-role-play as a classroom pedagogy neither impedes nor enhances learning in this context when compared to traditional teaching methods it does, however, appear to facilitate and support the process of deep learning. This is a contention that is also supported by a small number of research findings already existing in the area of science education (Ødergaard, 2003; Metcalfe et al., 1984). The implications of the qualitative data analysis of the group interviews are harder to define due to the range of perceptions and ideas presented by the students: some felt that simulation-role-play helped them to remember and understand the chemistry covered in the lesson whilst others claimed the opposite to be the case. Despite that, there was one point that emerged clearly from the analysis of the group interviews: students from both groups felt that simulation-role-play would not be effective in preparing them to answer examination questions. It was the students' general opinion that if simulation-role-play were to be employed as a classroom pedagogy then it would need to be followed by practice of examination questions. Unrecorded discussions with host teachers in this study indicate that that approach would be the one that they would take if they were to adopt simulation-role-play as a classroom pedagogy. This concern about the specific ability to answer examination questions was also reflected in numerous comments made by students that indicated that they felt that what was important was to learn to pass examinations, which was acknowledged not necessarily to be the same as understanding the chemistry. Accordingly, it was noted that some students suggested that they believed the predictability of the external examination questions justified a 'learn but don't need to understand' approach.

Another important theme that emerged from the qualitative data analysis was the students' reported belief that simulation-role-play is a suitable pedagogy for the representation of reaction mechanisms. Movement of the body can be used to represent the transfer of electrons and charge, which is key to the understanding of reaction mechanisms. This finding is shown to resonate with the existing literature on embodied learning, and it is argued to provide further evidence of the role that bodily movement plays in creating meaning. It is claimed in Chapter 5 that the study shows that students in the drama group developed more robust mental models than those in the practice examination-style question group for two reasons. Firstly, the embodied aspects of the lessons contribute to a conceptualisation of the macro dimension that was absent in the examination-style question group lessons. Secondly the use of simulation-role-play brings the student to the point of “metaxis” (Boal and McBride, 1979, p.74), the interface between their macro world and the sub-micro world. The student is able to make sense of the world at both levels simultaneously, and can therefore create alternative understandings of the world or ideas within which the drama is situated; leading to deeper level sub-micro understanding. With greater macro and sub-micro understandings, the drama group students are able to negotiate Johnstone’s (1991) triangle more fluently than their non drama peers and therefore form more robust mental models.

The existence and strength of those mental models was demonstrated by the fact that students in the drama group performed significantly better than those in the examination-style question group in response to the diagnostic question. The diagnostic question had been designed to assess deep learning, and therefore that finding is used in Chapter 5 to tentatively propose that the use of simulation-role-play promotes deep learning. However, as the results are dependent on a relatively small sample size and just one question, the conclusions in this respect can only be claimed for this group of students in the context of this study.

1.3 The future

There is scope for this research to be repeated with both a larger sample size and different aspects of the A Level Chemistry course. The analysis of the findings presented here also identifies the need for further research into the different types of learning that simulation-role-play encourages, with deep and surface learning being one model that might be considered further in the future (Donoghue, 2018).

Ultimately, this study is argued to have contributed to establishing a better understanding of the use of simulation-role-play as a teaching and learning pedagogy in the classroom when working with post-16 students; it has also provided teachers with data to inform their classroom practice. Further to that, this study has provided clear information that can be used to support trainers working in initial teacher training (ITT) as well as in ongoing continuing professional development (CPD). The hope is also that this study will raise and inform the important debate about the balance between the need to understand a scientific concept and the drive to pass examinations.

Chapter 2
Literature Review

The following literature review brings together the various strands of existing scholarship that underpin this study. In doing so, an overview is first provided of the reasons as to why the sciences, including chemistry, are considered to be difficult subjects to study. The particular areas under consideration in this regard are: the severity of grading in comparison to examination grades awarded across a range of different subjects, the use of multi-level thinking, the relevance of science the cognitive and linguistic demands of science, and, lastly, the construction of meaning in the sciences. It is argued that a scientist needs to function at multiple different levels or representation and thinking, and this is the lens through which the sections 2.1 and 2.2 are viewed. The focus of the chapter then shifts to the question as to why organic chemistry and organic reaction mechanisms are particularly challenging for students to study. Following the engagement with those questions, an outline is then provided of the role that drama has historically had within education, both across the general curriculum as well as in science education in particular. This literature review then concludes by discussing, in its final section, the use of visualisation in the construction of mental models and the ways in which drama, as embodied learning, may contribute to the construction of such mental models. Within the last section there is also a consideration of the question as to how the quality of mental models might contribute to the learning process.

2.1 Why is science considered to be difficult?

This study examines the use of drama (simulation-role-play) as a teaching and learning tool for a specific area of the A Level Chemistry course. Anecdotally, the sciences, including chemistry, have been judged to be ‘difficult’ subjects to study (Shayer and Adey, 1981; Johnstone, 1991; O’Dwyer and Childs, 2011). This chapter examines the reasons why the sciences might be considered to be difficult for students to learn, drawing first upon a range of reading relating to the three sciences (biology, chemistry and physics) and then focusing upon the kinds of challenges that are presented by chemistry in particular. The final section of this chapter reviews one aspect of A Level Chemistry, organic reaction mechanisms, and discusses the potential difficulties for students when studying them. It also explains why this topic is a suitable area to consider using drama as a teaching and learning tool.

2.1.1 Relative difficulty of examinations across the curriculum

In order to investigate the claim that science consists of ‘difficult subjects’, it is worth starting by looking at the literature relating to examination results at GCSE and A Level. The 2008 report by Science Community Representing Education (SCORE) (Coe et al., 2008) analysed data with respect to examination grades awarded in different subjects. This report identified that students claim to find STEM (science, technology, engineering and mathematics) subjects more difficult than others and that it is more difficult to obtain the higher grades in these subjects than in others. This assertion was supported by statistical analysis of grades awarded at both GCSE and A Level using the collated results of 29 different studies. These studies used a range of statistical tests to analyse the relative severity of assessment of 34 GCSE subjects and 33 A Level subjects. This meta-analysis demonstrates a high degree of consistency in determining the differences in grades awarded for both GCSE and A Level subjects across different studies and time. The axes of the graphs in Figures 2.1, 2.2 and 2.3 plot subjects against grading severity (the terms grade severity and grading severity are used interchangeably in the work of Coe et al., 2008) with severity denoting the measure of difference between the GCSE or A Level grades achieved by students with the same level of prior attainment. The more positive the grading severity for a subject is, the less likely it is that a student studying it will gain one of the higher grades when compared to subjects with a less positive grading severity.

At GCSE, the grade range between ‘easier subjects’ (that is, those with the most negative grading severity) and ‘harder subjects’ (those with the most positive grading severity) is typically one and a half grades. The implication of this is that the same student studying a ‘hard subject’, such as physics, mathematics, or chemistry would, statistically speaking, attain a grade that is one and a half lower than that which they would have obtained had they studied an ‘easy subject’ such as art. Figure 2.1 presents typical findings exemplifying this as reported in the work of Alton and Pearson 1996, cited in Coe et al., 2008, p.66.

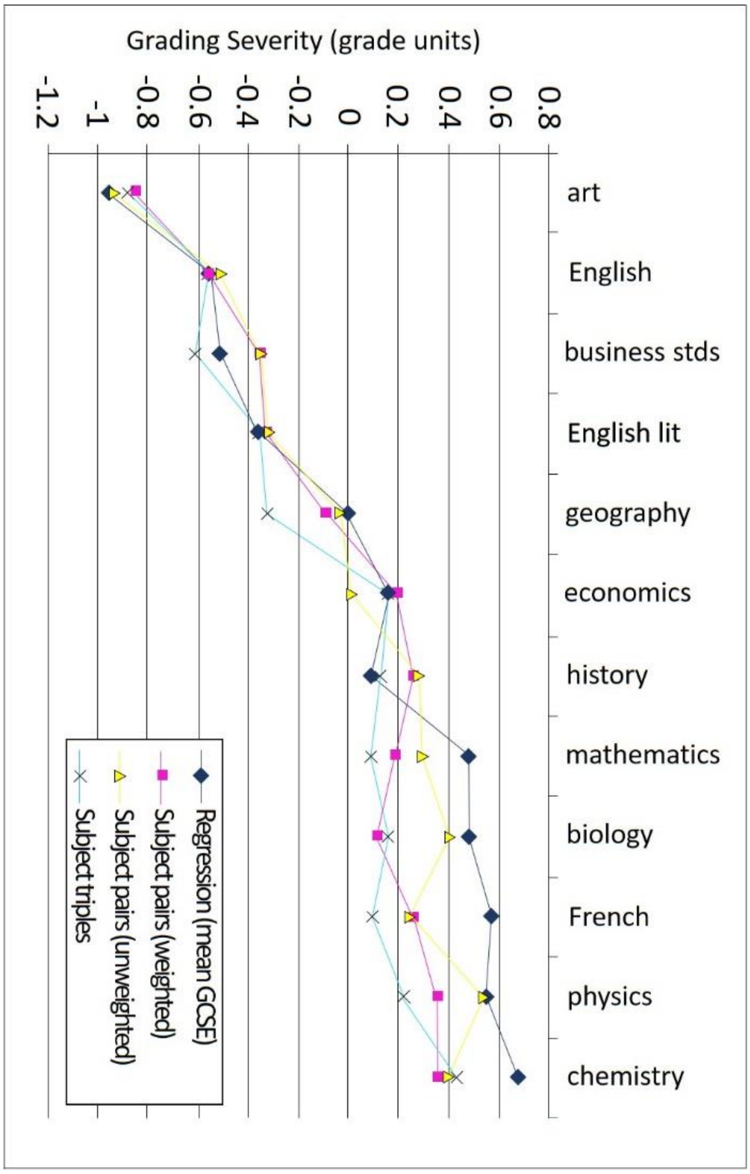


Figure 2.1 Analysis of degree of difficulty of a range of GCSE subjects (Alton and Pearson, 1996, cited in Coe et al., 2008, p.66)

At A Level, the difference between the ‘easiest’ and ‘hardest’ subjects was judged to be approximately two grades, with STEM subjects being located at the higher end of the continuum, with chemistry being most challenging of those. This can be seen in Figure 2.2 below. There are a range of other studies that also support these conclusions (Fitz-Gibbon and Vincent, 1994; Ofqual, 2015b).

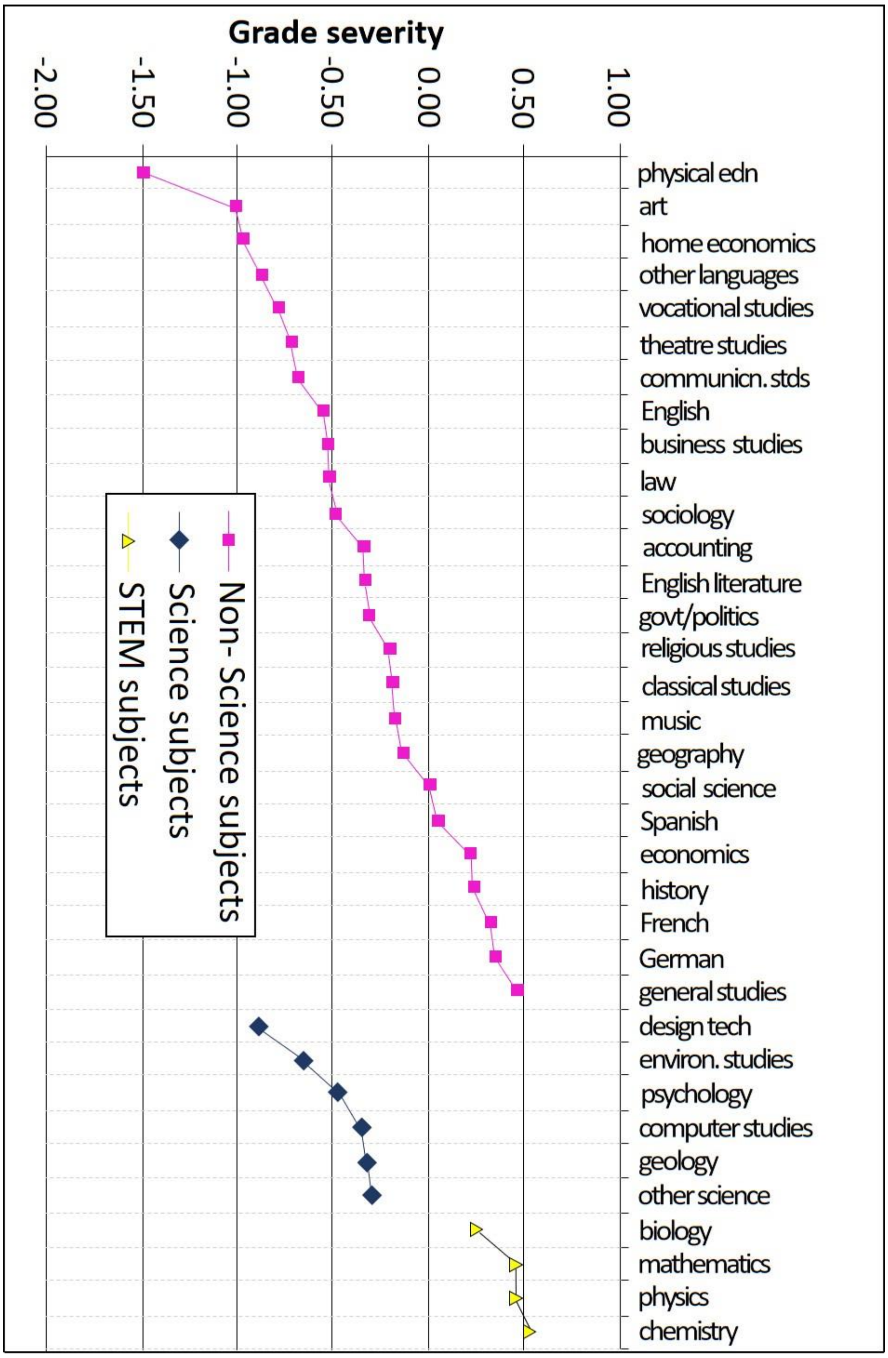


Figure 2.2 Average difficulty for a range of STEM and non-STEM subjects at A Level (Coe et al., 2008, p.69)

The code of practice for awarding bodies, set by the Qualifications and Curriculum Authority (QCA) for GCSEs and A Levels, does not dictate that there needs to be consistency in the degree of difficulty between subjects, merely parity of demand within the same subject, across the different examination boards and over time (QCA, 2008). As shown in Figure 2.3 below, the Department for Education curriculum review for 16-19 qualifications carried out by Dearing (Department for Education, 1996) was able to demonstrate that the degree of relative difficulty between A Level subjects remains stable over a period of time, with chemistry again consistently appearing as one of the subjects with the highest degree of grading severity.

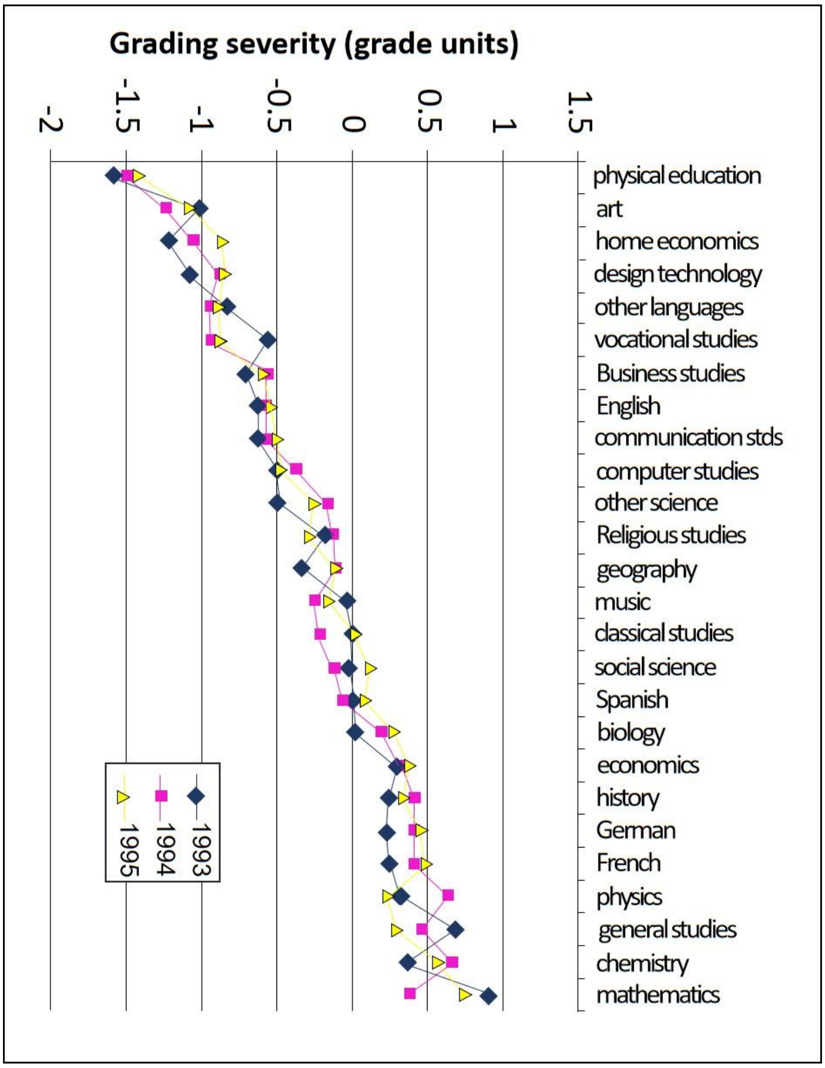


Figure 2.3 Longitudinal study of the relative degree of difficulty for different A Level subjects (Coe et al., 2008, p.47, based on DfE 1996)

Whilst it would appear that when students with similar levels of prior attainment take different GCSEs or A Levels, they achieve different grades depending on the subject, the interpretation of this data is subject to controversy. It has been argued by Goldstein and Cresswell (1996) and Newton (1997) there may be many other factors that influence the grades obtained by students. These factors might include, the amount of teaching time allocated in school, the quality of the teaching provided, and the students' intrinsic interest in a given subject. Whatever the case, it remains a fact that gaining high grades in STEM subjects, including chemistry at A Level, is more of a challenge for students, statistically speaking, than it is for them in other subjects. Sections 2.1.2 – 2.1.5 explore some of the reasons why the study of the sciences, chemistry in particular can be challenging for students.

2.1.2 Multi-level thinking

Some of the complexities of science can be appreciated when considering the idea of multi-level thought (Johnstone, 1991) that is summarised in Figure 2.4. Here it is proposed that, in order to operate as a skilled scientist, there is a need to be able to operate on three different levels, and to be able to move between these when the need arises. These three levels are: macro (concrete, tangible and visible), sub-micro (non-visible, for example particulate structures), and symbolics (formulae, equations and diagrammatic representations).

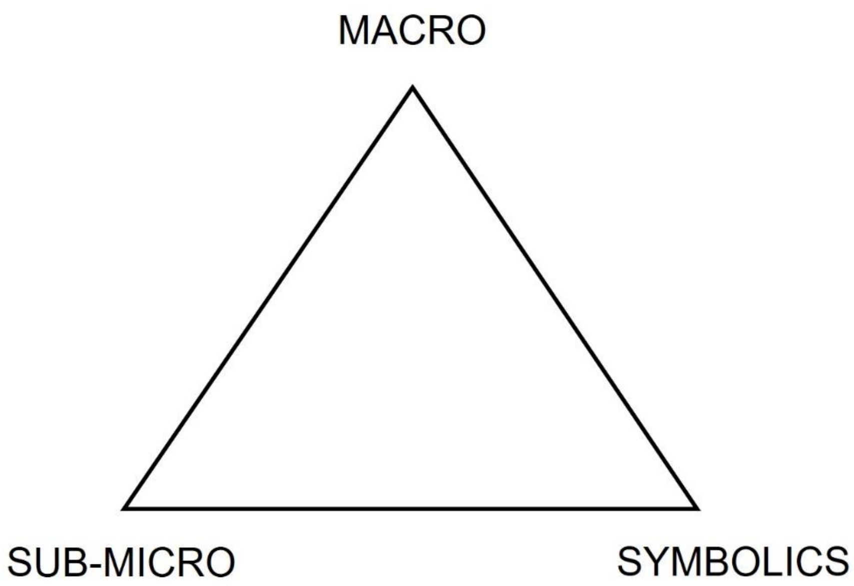


Figure 2.4 Triangle of multi-level thought in science, based on Johnstone (2010, p.24)

To give a contextual example, in physics students are taught about electric circuits. On a macro level, when studying that topic, students might observe a light bulb in a house being switched on and off. On a sub-micro level, rather than observing a bulb the students might be asked to consider the flow of electrons whilst, at a symbolic level, the task might be to draw circuit diagrams. Similarly, an example in chemistry might be the way precipitation reactions are represented. When the two colourless solutions of hydrochloric acid and lead nitrate are mixed together a bright yellow solid is produced which leads to an observation at the macro level. The sub-micro level explanation that is presented to the students in the case of this reaction is that hydrated lead and hydrated chloride ions come together to produce an insoluble, solid lattice. The reaction could also be represented symbolically using the equation shown in Figure 2.5.

$$Pb^{2+}_{(aq)} + 2Cl^{-}_{(aq)} \longrightarrow PbCl_{2\,(s)}$$

Figure 2.5 Symbolic representation of the formation of solid lead chloride

Johnstone (1991) argues that students are required to move between the different levels of representation. For example, they may need to interpret observable, macro phenomena, such as bulk properties of materials by referring to sub-micro phenomena, such as particles in solids, liquids and gases. In the physical sciences, students need to navigate the triangle referred to in Figure 2.4, with the three types of representation utilised in varying proportions, depending upon the demands that are made during a lesson. Johnstone (1991) maintains that this constant movement between these ways of thinking can be challenging for students. By its nature, chemistry, in many cases, demands that those that study it first consider reactions that might not appear to be relevant to them and then, engage in complex multi-level thinking. This way of classifying the levels of thinking is akin to that presented in the work of Chi (2005) who argues that it is challenging for students to accomplish transfers between ontological categories. Chi (2005) also suggests that there are emergent and direct processes: students observe (direct processes) and then make sense of those observations for themselves (emergent processes). The direct and emergent processes are, respectively, similar to the macro and sub-micro levels of thinking referred to by Johnstone (1991). An example of a direct process might be the observation of a candle burning, releasing heat to the surroundings, while the associated emergent processes are an appreciation of the numbers and types of bonds made and broken during the combustion being the cause of the exothermic nature of the reaction.

Tregaust (2003) draws on the work of Skemp (1974) using the terms instrumental understanding (knowing how) and relational understanding (knowing why) and how they are differentiated by the depth of understanding and the application of knowledge that the learner exhibits. Typically, instrumental understanding manifests as rote learning, for example, where a learner knows the rule and is able to use it; while relational understanding reflects meaningful learning in which the student knows what to do and why. Skemp (1974) emphasized the significance and the subtlety of the differences between the two types of learning, in that the students may know the same facts of the subject but their way of knowing is different.

Tregaust (2003) applies Skemp's (1974) definitions to scientific understanding. Here he asserts that instrumental understanding results from discrete representations, where the different representational types in Johnstone's (1991) triangle remain independent of each other, while relational understanding results from a fluency with, and integration of, the different representations in Johnstone's (1991) triangle, as seen in Figure 2.6.

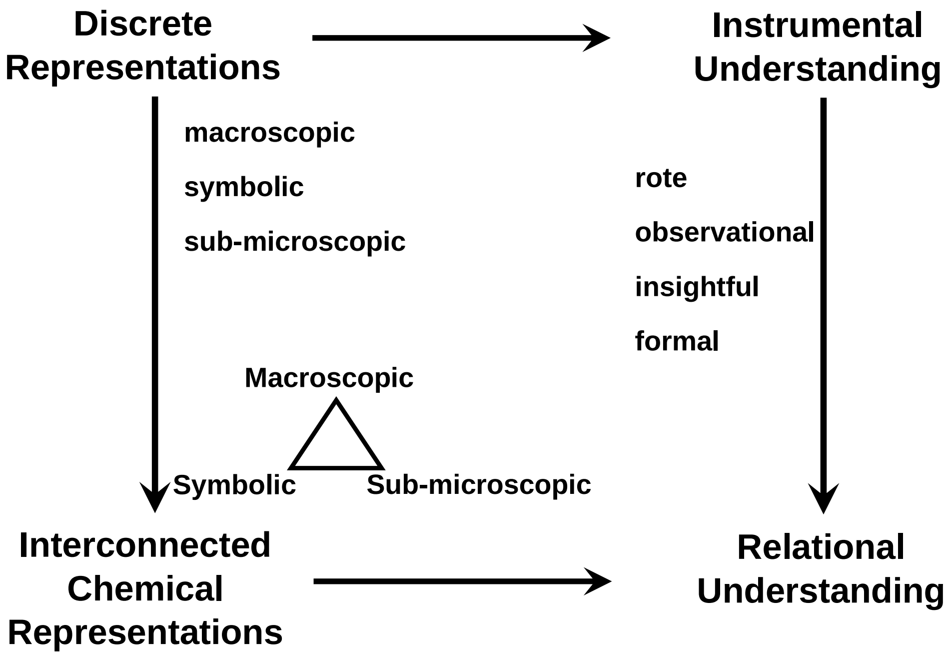


Figure 2.6 Relationship between chemical understanding and levels of chemical representation (Tregaust, 2003, p.1356)

One of the proposals from Tregaust's (2003) study was that students moved more easily from instrumental to relational understanding by linking macroscopic experiences to sub-microscopic and symbolic representations.

It follows that there is a need to facilitate shifting between the macroscopic and sub-micro levels. Taber (2013) suggested that this bridging can occur in a number of ways, including the introduction of symbolic representations and the use of dialogic teaching to allow students to explore meaning in their own ways, using vernacular language to describe and reinterpret the chemistry into the appropriate technical vocabulary. This can result in the descriptive macroscopic conceptualisations to deepen into explanatory sub-microscopic conceptualisations as presented in Figure 2.7.

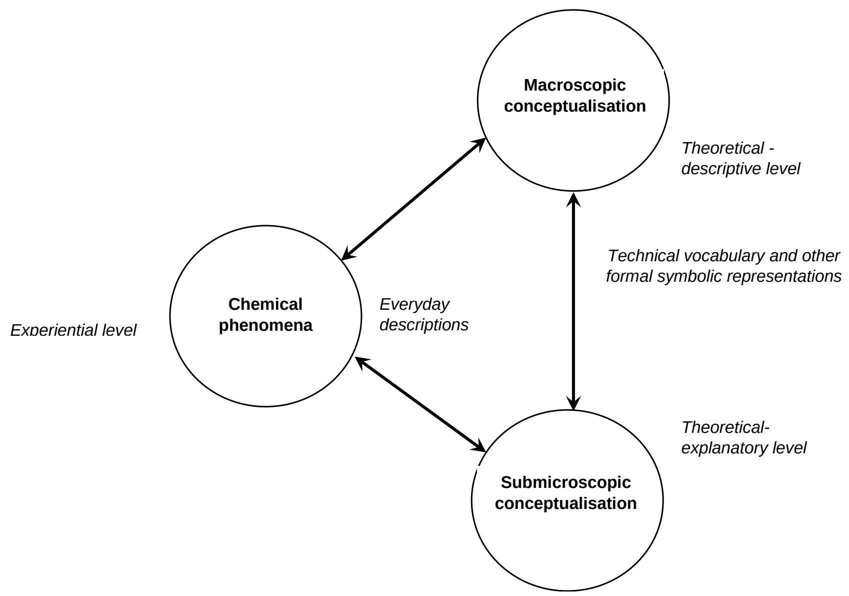


Figure 2.7 Re-descriptions between the everyday language of direct experience and formal representations of the conceptualisation of the subject at two distinct levels. (Taber, 2013, p.164).

Chi (2005) argues that modelling emergent (sub-micro) processes through the use of a range of instructional styles in the classroom, such as role play, might help to make clear links between the direct (macro) and emergent (sub-micro) processes. Resnick and Wilensky (1998) discuss how role play in the science classroom can facilitate the links that a student can make between their own world experiences and the emergent understanding of those experiences, i.e. move from direct to emergent processes. Jaber and BouJaoude (2012) worked with 46 students, aged 15 and 16, looking at the teaching of chemical reactions. They were interested in students' understanding on each of the three levels, macro, sub-micro and symbolic. Looking at pre- and post-test data, Jaber and BouJaoude (2012) found that students exposed to learning situations in which the links between these three levels of thinking were made explicit, by such means as the pointed consideration of the strengths and limitations of the model being used to represent a particular concept, did better in the post-intervention written assessments, to a statistically significant extent, than those students whose learning had included no explicit linking of the different levels of thinking. In addition, students who had considered the strengths and weaknesses of the scientific models make more complex links between the macro, sub-micro and symbolic aspects of the relevant chemistry when constructing mind maps, than did their peers who had not experienced these considerations. Within the current A Level specifications there is an organic chemistry subset that covers the chemistry of carbon-based compounds. One aspect of this subset is organic reaction mechanisms, an area that students commonly struggle to understand; this is a difficulty that was confirmed, in conversation with the researcher, by an A Level chief examiner (Otter, 2015) and an OCR Chemistry subject advisor (Otter, 2016). In the area of organic reaction mechanisms, typical macro experiences might consist of an organic synthesis in the laboratory, often preceded or followed by a teacher-led exposition of reaction mechanisms that includes a discussion regarding the stages of the reaction at a molecular level (sub-micro), followed by a schematic (symbolic) representation such as the equation shown in Figure 2.8.

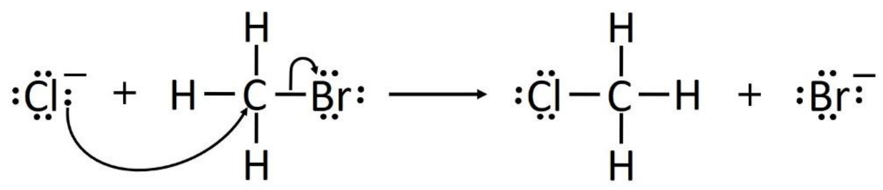


Figure 2.8 Symbolic representation of a nucleophilic substitution reaction

Organic reaction mechanisms do not feature in any of the GCSE Science or Chemistry courses provided in England and Wales. Accordingly, when students begin an A Level Chemistry course, none of them will have previously encountered organic reaction mechanisms, regardless as to whether their GCSE qualifications were in Dual Award Science or the individual sciences (Biology, Chemistry and Physics). This in turn means that any intervention studies in this area of chemistry as it is taught at A Level do not have to account for the potential influence of prior teaching and learning. This makes organic reaction mechanisms an ideal aspect of chemistry for this study.

Central to this study is the theoretical underpinning that for students to function well as chemists there is a need to be fluent in the use of Johnstone's (1991) triangle (Tregaust 2003; Kolari and Savander Ranne, 2004; Taber, 2013.) In order to explore the challenges facing students with this, sections 2.1.3 - 2.1.5 below each incorporate thoughts on how working with drama may assist in helping them to navigate Johnstone's (1991) triangle and promote deep learning through the lens of multi-level learning.

2.1.3 Relevance of science

Johnstone (1991) proposes that children learn by “asking questions, making observations and forming working hypotheses to meet immediate needs” (p.116) and compares this with the need, within science, to look for large, long-range theories and hypotheses to explain or systematise ideas. Johnstone (1991) goes on to argue that the questions we ask students in science lessons often have little relevance to their everyday lives; students are often required to draw on abstract ideas and notions, such as bond enthalpies and atomic structure, with no way of actually experiencing these ideas in a sensory way. Many of these concepts are abstract and need to exist as models in the mind of the student. For example, gravity cannot itself be observed directly, only the effects of it can be seen. Sulfur can be observed as a yellow powder, but the visualisation of atoms of sulfur requires the use of an abstract mental model. Driver and Bell (1986) clearly identify that one of the issues associated with students finding science difficult to understand stems from the challenge of linking real-world observations to scientific observations.

As Einstein and Infeld (1938) stated:

> Science is not just a collection of laws, a catalogue of facts, it is a creation of the human mind with its freely invented ideas and concepts. Physical theories try to form a picture of reality and to establish its connections with the wide world of sense impressions (p.46).

Tregaust (2003) talks of the macro (real world level) of Johnstone’s (1991) triangle as being experiments and experiences of the student. A Level Chemistry students may have the opportunity to carry out or observe experimental work in the laboratory, although these opportunities may be restricted in terms of time and/or equipment. In addition, the range of organic syntheses suited to the A level laboratory are somewhat limited. The use of drama could provide an alternative macro experience for students to assist them in accessing descriptive level conceptualisations in tandem with the ability to work with the appropriate technical vocabulary.

2.1.4 Cognitive demand in science

What follows is an overview of the links between student development and their ability to engage with aspects of science. The work of Piaget (1964) and Vygotsky (1978) are examined and common strands that could support the use of drama in teaching and learning of organic reaction mechanisms are considered.

Shayer and Adey (1981) claimed that one of the reasons why secondary school science is perceived to be difficult is the fact that many scientific concepts require a higher level of Piagetian thinking than is accessible to the students at that stage in their education. Shayer and Adey (1981) conducted research to establish the level of cognitive demand present in secondary school science courses. They used the actual levels of cognitive development of 12,000 students, aged 11-16, and then compared this to the cognitive demands made of these students in their science lessons. The measures of cognitive demands and cognitive development level that were used were based upon those developed by Inhelder and Piaget (1958) who proposed that the advancement of children's' ability to perceive, process and use data has a hierarchy. This hierarchy consists of a number of levels, summarised in Table 2.1.

Table 2.1 Summary of the main stages of cognitive development, based on Inhelder and Piaget (1958) and Shayer and Adey (1981)

Stage	Level	Approximate age	Characteristics
Sensorimotor	0	Birth-2 years	Learning through sensory experiences and manipulation of objects.
Pre-operational	1	2-7 years	Learning through pretend play. Still egocentric. Language develops. No appreciation of conservation of mass, length or volume.
Concrete operational	2A early concrete 2B late concrete	7-11 years	Beginning to develop logical reasoning. Can use inductive but not deductive reasoning.
Formal operational	3A early formal 3B late formal	11-adulthood	Developing the ability to think about abstract concepts, logical thought and deductive reasoning and systematic planning.

The concrete operational and formal operational phases are divided into early and late stages, referred to as 2A, 2B, 3A and 3B respectively. For the purposes of this study, there is no need to focus on the details of the differences between these; it suffices to be aware that most secondary school age students can be considered to be either concrete operational or formal operational thinkers, with a large proportion of those students in A Level studies having reached the formal operational stage.

It can be inferred from Table 2.1 that, in order to be able to complete many of the higher order tasks demanded in secondary and tertiary science courses, such as hypothesising and planning investigative work as well as utilising scientific models, there is a need for students to be operating at a formal operational level. Shayer and Adey (1981) made the assumption that a student working on one Piagetian level with respect to one scientific topic will also use this level of thinking with other scientific topics; they established that by the end of compulsory education in the United Kingdom (at age 16) less than 30% of students had reached early formal thinking (3A) and only 10% had reached late formal thinking (3B). Other work (Shayer and Wylam, 1978) indicated that girls aged 9-16 consistently performed less well than boys of the same age in tests relating to spatial awareness. This is a skill necessary for interpreting organic reaction mechanisms.

The influential Nuffield science O Level courses, introduced in the United Kingdom in 1962, were designed to support students through guided discovery via practical investigations. Curriculum materials for the three Nuffield science O Level courses were analysed for the level of cognitive demand across a range of topics. Figure 2.9 summarises the results for the Nuffield O Level Chemistry course. Although the paper is over fifty years old, the content remains relevant as much of the chemistry content is still part of the current GCSE specifications and the demand in terms of Piagetian levels remains the same.

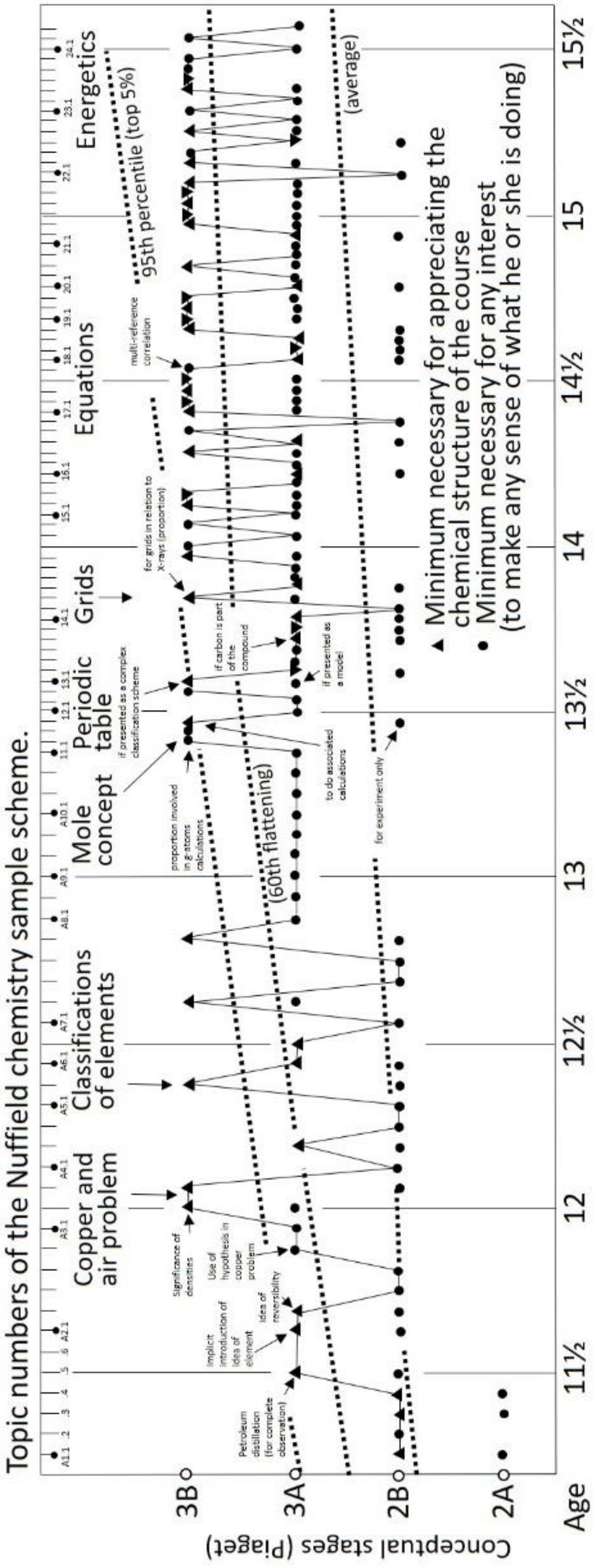


Figure 2.9 Cognitive demands in the Nuffield O Level Chemistry course (Shayer and Adey, 1981, p.11)

Interpretation of Figure 2.9 relies upon an appreciation of the fact that any cognitive demand on a level higher than that of a student's own conceptual development will result in that student's inability to fully understand the scientific topic in question. For example, the introduction of the classification of elements to students shortly after they have reached the age of 12 would demand thinking at a cognitive level that exceeds the conceptual development of the 95th quartile. This is the case with many chemistry sub-topics in the Nuffield O Level course related to moles, equations and energetics.

One point worth making is that if the periodic table is presented as a complex classification system, using atomic structure and associated reactivity linked to these structures, the cognitive level of demand would be in excess of the conceptual development of the 95th percentile of 13.5 year old students. However, if the periodic table is instead presented as a model, or as a visual representation based upon observable results of reactions, then the cognitive level of demand would fall to just below that of the 60th percentile (from between 3A/3B to 2B/3A). In other words, the use of macro observable phenomena, as opposed to invisible sub-micro phenomena, may assist students' initial understanding of a chemistry topic. It may be that drama could provide such a suitable macro experience.

It has been shown by Haley and Good (1976) that a large proportion of students up to the age of 18 are not able to function at a formal operational level of development. Lawson and Renner (1974), however, were able to demonstrate that a higher percentage of students aged 17-18 studying physics could function at the formal operational stage than randomly selected samples of students: 64% as opposed to 12%. This might be because students who have developed formal thinking skills perform well in summative science assessments, and so can be accepted to progress on to higher levels of study in science. At this formal operational stage of development individuals demonstrate an ability to make logical use of symbols that are related to abstract concepts. It is this skill that is required in order to work with the diagrammatical equations that represent organic reaction mechanisms. It has been proposed by Bliss (1995) that the use of a model in the classroom context allows students to engage with scientific thinking at a level appropriate for them at the time, but which also may allow students to experiment with its use and, in so doing, develop their thinking. Similar ideas informed the work of Gutierrez and Ogborn (1992) who proposed the use of physical models to assist in constructing mental models; these models, if used to enact scenarios could lead to deeper understanding. Goodstein and Howe (1978) similarly carried out research to support the idea that the use of concrete models to represent abstract chemical ideas helps students at the formal stages of development but are of less use to those still thinking primarily on the concrete level. Although levels of Piagetian development (Piaget, 1964) for students in this study will not be assessed, it is worth pointing out that the use of drama is a concrete way of accessing learning before translating learning into symbolic, formal, thinking modes such as two-dimensional representations of chemical reactions (the type of representations seen in written assessment items in examinations). A concrete model, in the form of drama could therefore act as a bridge between the different representations and levels of learning (such as used in Johnstone's (1991) triangle), as proposed by Taber (2013).

2.1.5 Language and learning

It has been claimed (Wellington and Osborne, 2010) that the language of science is rich in words that students may not be familiar with from their everyday discourse. In the case of organic reaction mechanisms, for example, many of the key terms used to describe them are very subject-specific: electrophile, nucleophile and chirality are not commonly used in general conversation. There are also common words such as 'substance' and 'mole' whose denotations when used within the field of chemistry are notably different from those of their everyday usage. In the case of organic reaction mechanisms these words include 'attack', 'lone' and 'polarity'. Mortimer and Scott (2003) argue that the differences between everyday social language and the language of science is one aspect of what makes science difficult for students to learn. If the situation is considered through the lens of Vygotsky's (1978) ideas of social constructivism, in which social interactions are held to be key to construction of meaning, this helps to advance the notion that group interaction and discussion results in individuals learning from each other and the teacher; resulting in a group construction of meaning about the language of a topic. The individual can then internalise and construct their own individual meaning. The use of drama as a teaching and learning pedagogy could provide a vehicle for students to work together, especially pertinent when co-authoring scripts. This in turn may assist students in deepening their understanding of the topic through constructing links between the macro, real world dimension of drama and the sub-micro, particulate level dimension.

2.2 Construction of meaning

Von Glasersfeld (1995) notes that the Greek Sceptic philosophers have long argued that

> It is logically impossible to establish the 'truth' of any particular piece of knowledge because the only rational access to that reality is through yet another act of knowing (Von Glasersfeld, 1995, p.6).

Herein lies the crux of constructivism: that irrespective of whether there is or is not a 'real' world out there, our own personal understanding of that world is an individualised construct based upon our interactions, both social and individual, with that world. These experiences may be shared but the individual constructs will be unique (Tobin and Tippins, 1993). By allowing students a range of social, shared, experiences, designed to give access to the required scientific concepts, we can assist in the building of these individual constructs.

As Tobin and Tippins (1993) comment:

> Science does not exist as a body of knowledge separate from the knowers. On the contrary science is viewed as a socially negotiated understanding of a set of socially negotiated

> understandings of the events and phenomena that comprise the experienced universe (p.4).

The issue here is one of being able to form a mutual understanding against a backdrop of individual constructs. Within a science classroom in which thirty students are working on acid-base neutralisation, for example, there will be, according to constructivist thinking, thirty different constructs: each student will have created their own internal meaning of the concept being studied. Many will be similar, as can be inferred through the observation of similarities in answers to assessment tasks, but each will stem from a unique internal understanding.

2.2.1 What influences the constructs that students build?

Driver and Bell (1986) identify that one of the issues associated with students finding science difficult is their prior knowledge, and they argue that previous experiences result in students coming to science lessons with preconceived ideas that are then used to construct meaning of the experiences they come across in the classroom. Essentially, students bring existing conceptions to bear on new experiences. Driver and Bell (1986) also describe how in learning situations we are “[c]ontinually hypothesising, checking and possibly changing our ideas when we interact with phenomena and with other people” (p.448). Organic reaction mechanisms, the chemistry content relevant to this study, will almost certainly have not been previously encountered in any ‘real-life’ context and will also not have been taught in school pre-A Level. All of those factors reduce the possibility of students having developed any pre-conceptions.

Scott and Mortimer (2003) returned to the work of Vygotsky (1978) with the intention of synthesising it into a consideration of the processes and factors involved in learning scientific concepts. Their reason for doing this was due to the perception that when people encounter new ideas in social situations they utilise “a range of modes of communication such as talk, gesture, writing, visual images and action” (Mortimer and Scott, 2003, p.9). Vygotsky (1934) talks of how individuals can build personalised learning through these social interactions, moving from the *social* plane to the *individual* plane. As a result, it can be argued that the generation of meaning is a dialogic process; through the process of bringing together language and thinking, meaning is constructed. This resonates with the work of Bakhtin (1981) who views the meanings that we construct as being a reflection of what we hear and sense around us. Bakhtin (1981) argues that we compare our sensory inputs to our own internal understandings of the world, assess whether or not they are in agreement, and use this to then either modify or reinforce our understanding. It therefore follows that the dialogic nature of the production of meaning can take many forms, from open discussion through to silent reflection on what is happening around us, i.e. from the social to the individual plane. Drawing upon this scholarship, it can be argued that if drama is used as a teaching and learning tool it will, by its very nature, include dialogic discourse.

Scott and Mortimer (2003) comment upon how the process of learning science involves being introduced to the language of the scientific community, while Vygotsky (1978) speaks about the content of language, dividing it into two categories: spontaneous (everyday) concepts and scientific concepts. The former are concepts formulated through everyday interactions and the latter are the formal concepts developed in specific disciplines such as chemistry. Bakhtin (1986) refers to the different languages used by specific communities of people: the language used by chemists when referring to the reactivity of metals, for example, will be different to the language used by jewellers or plumbers when working with those same metals. Wertsch (1993) asserts that individuals build up a bank of social language that they learn to use appropriately within any given context. These different social languages are learnt, rehearsed and refined in the social spaces of the classroom. Leach and Scott (2003) point out that the language used by scientists (and science teachers) is not just descriptive but is used to share meaning about “entities […]

and relationships between those entities [in order to] describe, explain and predict the behaviour of the world for specific purposes” (p.121).

As part of the work conducted in this study, the students involved were asked to predict the mechanism whereby a molecule of propanal is reacted with hydrogen cyanide in acidic solution. The students were required to be able to do a number of things: to identify the species involved in the reaction; to draw Lewis representations of these species; to use their knowledge of electron charge, bond polarity and electron density to predict how electrons in specific molecular environments would react; and to use the curly arrow convention to show the processes involved in bond making and breaking to identify the products of the reaction. In addition, they needed to use their understanding of the 3D structures of the reaction intermediate to determine whether there would be more than one product formed. This example demonstrates the complexity of the demands made upon the students; exactly what Leach and Scott (2003) are referring to when they say:

> Scientific knowledge is not there to be seen in the material world. Rather, it exists in the language, practices and semiotic systems used within specific communities to account for aspects of the material world. Learners will not stumble upon the formalisms, theories and practices that form the content of science curricula without being introduced to them through teaching (p.121).

Therefore, for an individual to construct any meaning for chemistry that is presented to them in an educational setting, they will need the opportunity to engage with the concepts and language of the topic in a meaningful way, facilitating transfer from the social to the individual plane. Vygotsky (1934) refers to this process of transfer as internalisation. With this in mind it can be argued that engagement in social activities such as constructing or enacting drama scripts is an appropriate classroom pedagogy, facilitating the consolidation of relevant knowledge and understanding of organic reaction mechanisms through social construction of meaning, potentially facilitating a bridge between the macro and sub-micro aspects of Johnstone’s (1991) triangle.

2.2.2 Linking Vygotskian and Piagetian stages of development

Piagetian levels of cognitive development, summarised earlier in this chapter, describe the progressive transition from a dependence on external world-based experiences, interpreted in a concrete, absolute way, to the more complex use of an internal self-constructed world that characterises the formal operational stage. At this stage of development individuals make unique sense of their world through the construction of abstract models. Piagetian (1964) stages can be linked to the work of Vygotsky (1978), in that, from the concrete operational stage onwards, students have a developing understanding of the social constructs of language. In Table 2.2, it can be seen that as the individual moves from the concrete operational to the formal operational stage their world view becomes more abstract, just as Vygotskian thinking fosters the view that the development of linguistic skills facilitates a similar process.

Table 2.2 A comparison of Piagetian levels with Vygotskian thinking

Piagetian level	Concrete/abstract	Vygotskian thinking
• Sensory motor • Pre-operational • Concrete operational • Formal operational	↑ Concrete, external, absolute. ↓ Abstract, internal, relative.	Social interactions facilitate developing linguistic skills and support formal operational functions ↓

The encouragement of the construction of socially-mediated understanding may improve students' ability to move fluently between the macro, sub-micro and symbolic levels of thinking required to operate as a scientist. This social mediation, supported by the use of drama, may involve more abstract levels of thinking than just working at a macro, observable, level.

2.3 The case for chemistry

Having considered the matters relating to why the school sciences are considered difficult to study, it is clear that there are issues common to all three sciences. As shown earlier, these relate to multi-level thinking, relevance, cognitive demand and the construction of meaning. Since the area of chemistry focused upon in this study has already been identified, this section of the chapter considers the study of organic chemistry, with particular reference to organic reaction mechanisms.

2.3.1 Issues associated with teaching and learning organic chemistry

O'Dwyer and Childs (2011) identify that, even though organic chemistry comprised approximately 20% of the chemistry curriculum in Northern Ireland, and approximately 25% of assessment marks, the chief examiner of the State Examinations Commission (2008) highlighted a paucity of candidates choosing to answer organic chemistry questions at GCSE level. In a similar vein, there were also comments from the chief examiner of the state examinations commission in Northern Ireland relating to students taking A Level Chemistry having performed poorly when required to draw molecular representations (State Examinations Commission, 2008). Comments from reports by the UK's A Level chief examiner (OCR, June 2009) also identified that candidates scored less well on the questions relating to reaction mechanisms in comparison to those concerning other aspects of chemistry. O'Dwyer and Childs (2011) questioned 276 students, age 16-18, and found that 59.7% of respondents thought that organic chemistry was difficult. The most commonly given reason for this (31.5%) was the extent and detail of the content. O'Dwyer and Childs (2011) surveyed and collated the perceptions that students had regarding the difficulty of particular aspects of organic chemistry and the results can be seen in Figure 2.10.

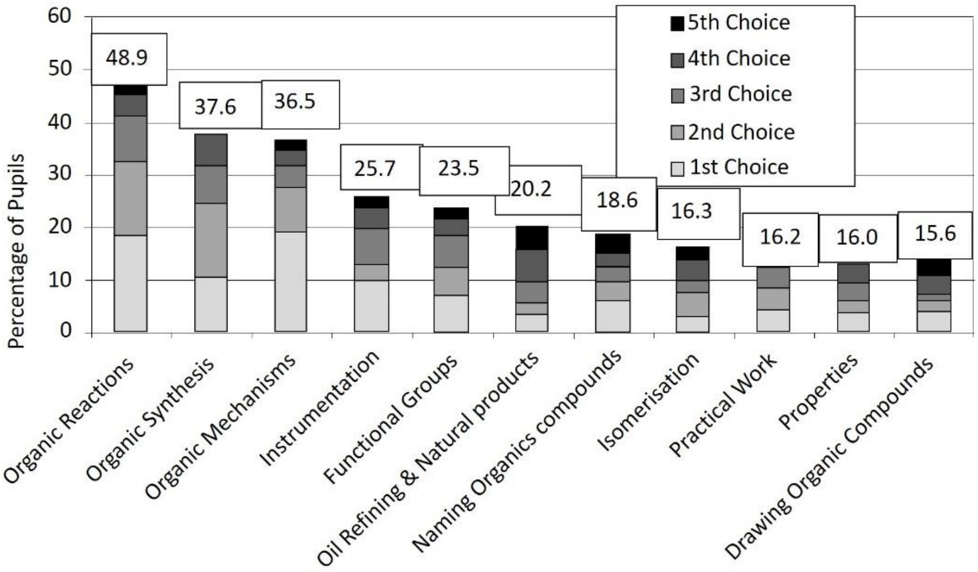


Figure 2.10 Top five most difficult organic chemistry topics, as rated by second level pupils (O'Dwyer and Childs, 2011, p.62)

As Figure 2.10 shows, organic reactions, organic synthesis and organic mechanisms were judged to be the top three most difficult topics, using aggregated scores. Organic mechanisms were judged to be the most difficult, as judged by first choice, by the highest number of respondents (19.2%). Students' perceptions were in line with their performance in diagnostic tests carried out at the same time as the questionnaire. It can be seen in Table 2.3 that reaction mechanisms yield the lowest average score when compared to the other topics, indicating that this is an area of difficulty for students.

Table 2.3 Summary of the students' performance in diagnostic questions (O'Dwyer and Childs, 2011, p.63)

Question	**Topic**	**Attempt (%)**	**No attempt (%)**	**Average score (%)**	**Mark order**
1	Drawing	94.6	5.4	77	1
2	Naming	90.6	9.4	45	8
3	Isomerisation	84.1	15.9	66	2
4	Electrophilic attack	76.8	23.2	51	5
5	Reaction types	81.2	18.8	46	7
6	Reaction synthesis	66.3	33.7	47	6
7	Reaction mechanisms	**51.1**	**48.9**	**29**	**9**
8	Classification	77.2	22.8	56	3
9	Properties	72.8	27.2	55	4

Teachers identified organic reaction mechanisms as the second most difficult topic to teach, citing the difficulties the concepts posed for the students, particularly in terms of visualising the steps of the mechanisms (O'Dwyer and Childs, 2011). Organic reaction mechanisms have also been identified as being difficult by both Ratcliffe (2002) and Johnstone (2006).

2.3.2 What are the challenges for students in writing organic reaction mechanisms?

Ault (2010) defines a reaction mechanism as "an atomic or molecular description of how the atoms and molecules of the starting materials become the atoms and molecules of the product" (p.937).

The processes occurring during organic reactions and the accompanying rearrangements at a particulate level are an integral part of the chemistry curriculum for all of the A Level specifications currently taught in England and Wales (AQA, 2017; Pearson Edexcel, 2018; OCR, 2019). Organic reactions are studied at GCSE level, but not the mechanisms by which they occur. The study of organic reaction mechanisms, in the official school curriculum, commences during post-16 studies.

The use of the curved or curly arrow as a way of representing electron movement during mechanistic processes was first proposed by Kermack and Robinson (1922). The publication of Morrison and Boyd's textbook (1959) saw the mainstream introduction of electron-pushing formalisation (EPF) using curly arrows as a way of explaining and representing organic chemistry reaction mechanisms. This system is now an integral part of chemistry education, included in A Level, undergraduate and post-graduate chemistry courses. EPF allows a chemist to propose organic reaction mechanisms in a written format. As Loudon (1995) summarised "it is a symbolic device for keeping track of electron pairs in chemical reactions" (p.89).

EPF works with particulate level representations to determine how electron movement within, or between reactants, results in the formation of products. The curly arrows represent the movement of electrons from electron-rich areas, known as the source, to areas of electron deficiency, called the sink.

By convention the movement of a pair of electrons is represented by a double-headed arrow, whilst the movement of a single electron is represented by a single-headed arrow (Bhattacharyya and Bodner, 2005). Figure 2.11 shows examples of these two representations.

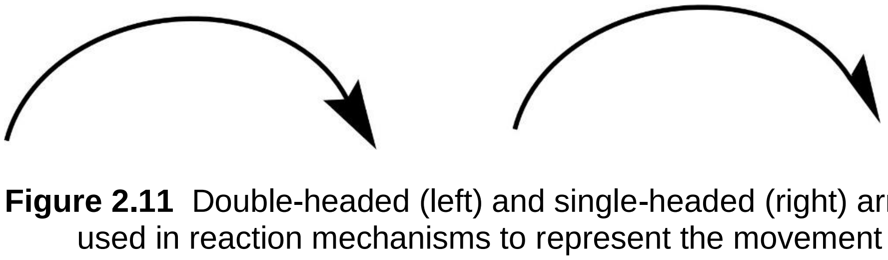


Figure 2.11 Double-headed (left) and single-headed (right) arrows used in reaction mechanisms to represent the movement of two electrons and one electron respectively

The consequence of electron movements that break existing bonds and form new ones is that chemical reactions occur and new products are formed. An organic reaction mechanism manifests as a diagrammatical representation of the sequential movement of electrons from start to end of a reaction. An understanding of these processes, coupled with an ability to represent these changes, enables skilled organic chemists to both predict the likely outcomes of organic reactions and to explain how new products have been formed in a reaction.

Ellis (1994) identified three main difficulties in organic chemistry, including reaction mechanisms: there are no problem-solving algorithms; there is a need for three-dimensional thinking; and there is an extensive new technical vocabulary that must be mastered. Furthermore, Grove, Cooper and Rush (2012) proposed that visualisation is key to learning chemistry, since there is an expectation in organic chemistry that students will be able to represent atoms, molecules, ions and electrons and to learn to translate and navigate between different models in meaningful ways. As discussed earlier, students will be expected to navigate between macro, sub-micro and symbolic levels of thinking (Johnstone, 2010).

Whilst there exist a number of papers on suggested strategies for teaching reaction mechanisms using curly arrows (Friesen, 2008; Vosburg, 2008), there appear to be a limited number of studies looking at the demands facing students when working with them. When considering what happens during the construction of a reaction mechanism, Bhattacharyya (2013) points out that there are no explicit definitions for “mechanistic reasoning [or] mechanistic thinking” (p.1287) and there is also little research on how learners develop competency in using the curly arrow notation, nor on how they use this to construct or interpret reaction mechanisms. Bhattacharyya and Bodner (2005) worked with fourteen, first semester, organic chemistry undergraduates who were asked to predict the reaction mechanisms whereby target molecules were produced from specified reactant molecules. In order to reduce any potential of subject knowledge as a confounding variable, course textbooks were made available for reference. The undergraduates completed the given problems using a think-aloud protocol. The researchers concluded that the curved arrows used in EPF held no physical meaning for the undergraduates. The arrows symbolised little to them, and this was taken to indicate a lack of understanding as to the role of this formalisation in explaining *how* and *why* a reaction takes place. As a result, the undergraduates did not see the arrows as a way of working out how to predict or explain a reaction. One undergraduate went as far as saying “It’s basically playing around; I’ll try and force it to work; it gets me to the product” (Bhattacharyya and Bodner, 2005, p.1405).

In a further small-scale study, Ferguson and Bodner (2008), working with a sample of sixteen first year undergraduates, again concluded that the process of drawing curved arrows was purely mechanical and had little, if any, intrinsic meaning for those students. The researchers also reported there was heavy reliance on memorising specific reactions as opposed to developing an understanding of how to work out the relevant reaction mechanism. This indicates that the dependence on memorisation, as opposed to an understanding of this topic, is a commonplace strategy at both pre-university level (O’Dwyer and Childs, 2011) and undergraduate level (Ferguson and Bodner, 2008).

Work by Grove, Cooper and Rush (2012) involved a much larger sample size, with 2,200 mechanisms collected from some 300 chemistry undergraduates. Using an electronic software package allowed the scribed mechanisms to be recorded onto computer tablets. Researchers were then able to analyse an interactive version of all that had been recorded of the undergraduates’ work. From this extensive database Grove, Cooper and Rush (2012) were able to report that, depending on the reaction, between 30% and 60% of participants did not engage in the activity provided, and that 15-20% added in curved arrows *after* predicting a product for the reaction. Across this longitudinal study, these figures remained reasonably stable, indicating that the approach adopted by an undergraduate remains stable across the time of their degree, irrespective of the reaction mechanism under question.

Grove, Cooper and Cox (2012) carried out a further study, in which it was found that the majority of undergraduates felt it unnecessary to use, or were unable to engage with, the construction of reaction mechanisms via EPF. Grove, Cooper and Cox (2012) were interested in whether the undergraduates who succeeded in using EPF used these ways of thinking to good effect for reactions of increasing complexity. They worked with 399 undergraduates and found that for simple reactions there were no significant differences in success rates for those that used mechanisms and those that did not. e.g. using retro fitting arrows to products or relying on memory. For more challenging, complex, reactions the students that used mechanisms scored significantly higher than those that did not use mechanistic strategies.

2.3.3 What do students need in order to be able to work successfully with organic reaction mechanisms?

In order to be able to predict reaction mechanisms Grove, Cooper and Cox (2012) suggest the following are the types of question that learners will need to ask themselves:

- At what position in the reactants does the arrow start?
- At what position does the arrow end?
- What does the arrow actually mean?
- Do I use a single-barbed arrow or a double-barbed arrow?
- Is the process concerted or does it happen over the course of several steps?
- If the latter is the case, what do the intermediates look like?
- How do the intermediates themselves react to subsequently form the product?

(p.852)

Adnan, Hill and Reid (2004), working with first year undergraduate chemists in Scotland, proposed that the following additional questions are important:

- What class of organic compound is this?
- What kind of reaction can I expect it to undergo?
- Are there any aspects of reactivity of the compound I need to bear in mind when deciding on the likely product(s) of the reaction?
  (p.40).

It would seem that, in order to succeed in understanding organic reaction mechanisms, there is a need to see that each one represents a unique process. These processes are logically constructed and rely upon an interpretation of molecular structures in terms of electron density and then use the movement of electrons to predict intermediates and final products. The movements of these electrons are formalised to represent their movements from areas of high electron density to areas of electron paucity, leading to the making and breaking of bonds. Each reaction is a new scenario and there can be no reliance on algorithms.

2.4 The use of drama in education

Having now identified organic reaction mechanisms as an area of chemistry that has challenges for the learner, this section aims to map an overview of how the use of drama within an educational setting developed, as well as its current place within. It also reviews the ideas of a number of influential drama educators and the changing perceptions of the purpose of drama in education.

2.4.1 The historical background

The concept and practice of drama has a long and complex presence within the history of human culture and thought. The word drama is derived from the Greek word dromenon, meaning ‘a thing done’ (Wood, 2012), and relates to using the body to explore or represent meaning. In East Africa, the Griot (travelling storyteller) has a long tradition of chronicling the oral history of tribes through the use of acting, singing and dancing. Kascula (1999) describes how these chroniclers have historically been a repository of information, to be repeated at will, for tribal people using the oral tradition. History tells of Greek tragedy and comedy being established with Thespis, the alleged founder of Athenian tragedy, who was reported to have won the first official tragic competition in *c*.533 BCE (Sommerstein, 2002).

In England the theatre, and the public performance of dramas in general, has a chequered history. Mediaeval dramas in England often revolved around ecclesiastical events, for example, the Corpus Christi and Mystery plays, where scenes from the Bible were staged on carts that were taken through city streets to enlighten and entertain the populace, with drama serving to familiarise the masses with stories from the Bible (Johnstone,1979). The later Elizabethan and Jacobean eras saw a great rise in the number of public playhouses staging non-Biblical performances, although this rise of the theatre was curtailed by the puritanical government that prevailed after the civil war. Oliver Cromwell, backed by the army, governed England as Lord Protector from 1653 until his death in 1658 and activities deemed as being pointless or immoral were disapproved of and theatres, judged to fall into this category, were closed. This situation was subsequently reversed with the Restoration (Straub, Anderson and O’Quinn, 2019). The nineteenth and early twentieth centuries saw the emergence of a tradition of music halls and community productions used as forms of entertainment and as a means to bring communities together (Straub, Anderson and O’Quinn, 2019).

For the purposes of this study it is necessary to outline the difference between drama and theatre. The latter uses drama for the purposes of performing to an audience, while drama is the use of body and mind to explore issues, without the necessity of an audience. Drama, in its broadest sense, makes use of a written composition or script as the basis for individuals to tell stories and explore meaning via the use of non-verbal actions (performance) and dialogue (Marsella, Johnson and LaBore, 2000).

The perceived purpose and nature of drama in education is continually evolving. The “Drama Education, Survey 2” (The Department of Education and Science, 1968) attempted to define drama, describing it as an aspect of English education in school resulting in expression through use of the body. The following section charts the place of drama in the English education system, particularly in the twentieth and twenty-first centuries, where it can be seen that this simplistic view is more nuanced in reality.

2.4.2 The history of drama in education

Drama was enshrined as an entitlement for all secondary school students as part of the English curriculum (Department for Education, 2007), with the activity of “improvising, rehearsing and performing play scripts and poetry” (Department for Education, 2014a, p.7) mandated in the 2014 KS4 National Curriculum. This has not always been the case and the role of drama in education has been contested over time.

Things have changed radically from the Puritan mindset that sought to close theatres in the seventeenth century (Baker, 1879). Wesley, the cleric and theologian who was a leader for the Methodist movement in the Church of England in the 18th century, supported the view of education for the lower classes as a route to prepare for employment. There was to be no place for play, and as a consequence no place for drama, in the education system under Methodist ideals (Hilton and Shefrin, 2009).

One of the earliest chronicled examples of the systematic use of drama in the classroom can be found in the work of a relatively unknown innovator called Finlay-Johnson (Cyr, 1920; Bolton, 1985). This headteacher of a village school in Sompting, Sussex, during the early part of the twentieth century, believed that drama could be used as a means of mastering curriculum content. Finlay-Johnson, rather than allowing her students to play in an unstructured way, advocated drama as a vehicle for helping them to make sense of subject matter (Finlay-Johnson, 1911). Self-expression was not a driving goal of these drama activities; as we will see, this was only claimed to be important later on in the history of drama in education. One example of Finlay-Johnson's teaching practice in this regard involves the dramatisation of historical events in order to reinforce factual learning. Finlay-Johnson, attested that the child-centred approach served the traditional requirements of education as a transmitter of knowledge:

> I feel convinced that my students have learnt far more of the English language, history and withal romance than could ever have been taught by means of blackboard, columns of classified words and Latin roots (cited in Cyr, 1920, p.25).

Finlay-Johnson's (1911) publication gives practical guidance on the use of drama in mathematics, history, English, geography and science. In terms of the latter, a transcript is included of a play produced by students enacting the reasons behind the relative growth rates of flowers. This method of using drama as a pedagogy to assist students in accessing curriculum content was not to re-emerge again for another 50-60 years, and is in direct contrast to the way that drama was to be used in an educational context in the interim years of the twentieth century and beyond.

2.4.3 Drama in education – for what purpose?

Finlay-Johnson (1911) rationalised the use of drama to access subject knowledge, whilst figures, writing later, sought to utilise it to access the affective domain in terms of student attitudes and feelings. Finlay-Johnson's (1911) ideas were in contrast to the philosophy of education developed by Cook (1917), a teacher at the Perse School in Cambridge, who, also in the early years of the twentieth century, used dramatic method as a vehicle for students to experience, enjoy and sense. Cook (1917) argued that play is the natural way to learn and through doing and experiencing, children will naturally acquire knowledge. Cook (1917) spoke of how "interest is what matters" (p.9) and claimed that

> [t]here is more of the average Puritan in the school master [sic] than is generally recognised, and, although he [sic] does not frown upon play in its place out of school, he [sic] finds it very hard to see how play and study can be carried out at one and the same time (p.19).

For Cook there was not a tangible body of knowledge to be learned through drama, only the art of drama and acting itself. The primary importance of drama was to help students begin to learn the art of acting, to become acquainted with stage conventions and techniques of voice projection, drama was not viewed as a tool to be used in aid of learning of any conceptual ideas. Cook (1917) argued that if the students' attention is on the techniques required to portray a dramatic event, then they will automatically make a connection with feelings and emotions generated in response to the drama.

The work of Finlay-Johnson (1911) and Cook (1917) exemplify two different understandings as to the purposes of drama in the classroom: for the former, it is to access formal, knowledge driven content; for the latter, it is to leave the student to explore freely their thoughts and emotions through child-centred drama. In the former there is a correct answer, in the latter there are no correct answers. Dewey (1921) spoke of a traditionalist view in which the purpose of education is the transmission of knowledge, referred to as the empty jug model wherein information is seen to be ‘poured’ from the teacher into the student. The work of Finlay-Johnson (1911) lies closer to this model than that of Cook where there is ‘correct’ subject knowledge, but through the use of drama in the classroom the child is partly unpacking meaning for themselves. An alternative view of the purpose of education can be seen to be evidenced in what Bolton (1985) refers to as the “Rousseauesque” (p.152) notion which makes central the perceived uniqueness and importance of the individual child. This links to Dewey’s (1921) work in which he speaks of the child becoming “[t]he sun, about which the appliance of education revolves; he [sic] is the centre around which these are organised” (p.35).

In contemporary times, this might be referred to as child-centred learning. Vocabulary used by educationalists espousing these notions during the early years of the twentieth century included Lord Baden Powell’s expression “learning through self-expression” (Baden-Powell, 1929) and Cook’s (1917) “play-way” (p.98) and generally emphasised the idea of the child as an individual. The approach taken by Cook when using drama in schools was in line with this thinking. Children were encouraged to develop their own thoughts and feelings. The Hadow report (Board of Education, 1931) argued that the curriculum of the primary school “is to be thought of in terms of activity and experience rather than knowledge to be acquired and facts to be stored” (Section 75).

In addition, Dewey (1920) argued that activity in the classroom should have some purpose and that it is this classroom environment that can influence the learning of the child, i.e. the teacher can mould the learning by providing direction. This presents something of a paradox when considering that the ‘freedom’ of the child’s learning is to be moulded by the teacher. Bolton (1985) argues from a personal perspective that it is the free, unfettered, view of drama that has led to a suspicion of the value of drama in education. He argues there is a paradox, in that within the twentieth century, which he describes as being a scientific and technological century, traditionalists might have more readily accepted drama as part of the school curriculum had it demonstrated concern with knowledge, rather than self-expression.

The role of drama in education continued to be the subject of debate throughout much of the twentieth century. Bolton (1984) notes that there were two prevalent, and distinct, opinions as to what the utility of drama was: on the one hand there was the idea that it was for “the refined expression of the stage” (p.22); on the other hand was the perception that it was, instead, for “free expression of children’s own colloquial banalities” (p.22). Furthermore, Bolton (1985) indicates there was a tension between these two views and postulates that there was:

> [g]overnment inspectors’ concern about the need for teachers to be more specific about what they were actually teaching through drama […]. To government observers, the one aspect all teachers should be concerned with was the obvious *means* of expression – speech (p.153).

Regardless as to whether or not this was the driving force, there arose a movement that pushed for the development of speech and speech training through drama. There was much effort expended in the attempt to impose a certain style of speech (received pronunciation) in theatrical productions, for example in 1906 Fogerty opened the Central School of Speech Training and Dramatic Art in the Royal Albert Hall, London (Shepherd, 2019); this was the first specialist speech college to make use of drama as a vehicle for speech training. Cox (1970) argued that if the focus was placed solely upon speech development and training then this approach to the use of drama might stifle some aspects of creativity (cited in Bolton, 1984).

By the time Slade, a former education authority adviser for the City of Birmingham and an influential figure in drama education, arrived on the scene, he was advocating a shift from drama being about a play, to drama being about the position of the performing subject in a play (Slade, 1925). This is in stark contrast to the model described above, in which speech is very much the primary focus. Slade (1925) defined child drama as an art form in its own right with the child as the natural actor. He deplored the use of public productions and the use of scripts and instead promoted spontaneity of expression. Slade was less concerned with what was expressed and more concerned about the freedom of students to explore their own thinking and feelings about ideas.

During the 1960s and 1970s there were two practitioners, Way and Heathcote, who typified the differing views of the role of drama in an educational context. Building upon the ideas of Slade (1925), Way (1967) considered the function of drama in education to be the development of the individual through the processes of performance and enactment, taking the child's experience as the starting point. As part of his work in that regard, Way (1967) devised and set out a series of exercises that aimed to help students to develop their concentration, sensitivity and imagination. Bolton (1985) comments upon how Way's approach, with its attention to life skills rather than dramatic skills, reassured some teachers at the time, who might otherwise have been concerned about the perceived lack of purpose and content in drama lessons. Way and Slade also worked in collaboration in order to develop a student-centred course for trainee teachers. The style of creative drama advocated in this training has, implicit within it, assumptions that there should be an emphasis on the individual using a wide range of activities with a focus on the importance of intuition (Jackson, 1990).

This mode of thinking became more accepted in the1960s, a decade that also saw the publication of the Plowden report (Central Advisory Council for Education (England), 1967) which, regarding the use of drama in schools stated

> It is significant that the liveliest drama in the first year of the secondary school is of the unscripted kind […]. Certainly, though some primary school children enjoy having an audience of other children or their parents, formal presentation of plays on a stage is usually out of place (p.218).

At the same time as Way's work was gaining influence, Heathcote's profile had also risen to such a degree that she was held to be an expert in the field of children's drama (Wagner, 1976; Courtney, 1989). In contrast to the work of Slade or Way, in which direct experience and empathy were understood to be at the heart of a child's experience of drama, Heathcote's critical focus was, instead, upon the content or subject matter of a particular dramatic experience (Wagner, 1976). As such, Heathcote's approach can be seen to have a certain amount in common with the earlier work of Finlay-Johnson (1911). The important difference between the work of Heathcote and Finlay-Johnson is found in the fact that, whilst Heathcote sought to consider drama, not only in relation to particular facts, but also to the more universal implications of a topic, Finlay-Johnson was primarily interested in factual content of the curriculum. Heathcote planned thematically, for example, using pirates or mediaeval life in a monastery as topics through which to explore ideas. Central to Heathcote's teaching technique was the idea that students should be allowed to make as many decisions about the drama as possible (Wagner, 1976); the intention behind that being to enable the dramatic experience to be fluid and the students to solve problems reactively (Heathcote, 1991). Heathcote encouraged her students to take their interest in the world as the inspiration for their drama, and every child needed to function as an 'expert'; this practice led to the development of the term "Mantle of the Expert" (Heathcote and Bolton, 2008, p.4). In their reflections upon the nature and role of the

Mantle of the Expert, Heathcote and Bolton (2008) root their thinking in Vygotsky's (1934) social development theory, which draws upon the influential role of social interaction in the development of cognition as well as the part that community plays in helping individuals to construct meaning (Vygotsky, 1978). Heathcote's techniques in the use of drama allow social interaction and, combined with the skilful guidance of a teacher or other 'expert', a child will be able to construct new meaning. The adult teacher establishes first the context that is to be explored and then, through the investigation of aspects of this context with students, there follows a gradual move towards student ownership and understanding of the issues discussed. Once this progression has been accomplished the students will be able to take on the roles of different stakeholders involved and, in this manner, further develop the Mantle of the Expert.

Pemberton-Billing and Clegg (1965) claimed that whilst children have little control over their own life their participation in drama allows them to assume some control in the attempt to make sense of their surroundings. Through dramatic invention, the argument went, children are able to both make discoveries and develop as individuals. The development of that which Pemberton-Billing and Clegg (1965) termed "mental mobility" (p.23), understood as being the imagined transference of oneself into another situation, allows for increased awareness for the student. Pemberton-Billing and Clegg (1965) also argued, building upon that idea, that participation in drama requires students to communicate a wide selection of thoughts and ideas; the result of students' utilisation of imagination in order to organise and articulate their thinking. Drama, Pemberton-Billing and Clegg (1965) contend, provides a child with the opportunity to "practice and improve his [sic] ability to organise his [sic] ideas" (p.27); as such they also explored the idea that using drama could lead to the development of sensitivity in students, as a degree of empathy is required in order to imagine oneself in the persona or circumstances of another person. This idea of the role of empathy when using drama also offers a connection to the work of Boal and

McBride (1979) who outline, as a key feature of the use of drama in education, a relationship that exists between the imagined and the real that they refer to as “metaxis” (p.74). Whilst an actor, when performing in a drama, generally assumes and explores the role of another they are still also, at the same time, engaging with some part of themselves. The drama exists as the interface between the participant and their fictitious world. Boal and McBride (1975) claim the actor is able to make sense of the world at both levels simultaneously and can therefore create alternative understandings of the world or ideas within which the drama is situated.

In a similar vein, Bolton (1979) defines drama as primarily being involved in working with values attributed to a concept or situation and proposed that since drama works at both a subjective and objective level it is a suitable vehicle for working with value judgements. Courtney (1989) uses different vocabulary to describe a similar idea. The term “as if” is described as implying “the transformation of being into something else; turning the *actual* into the fictional in order to work with it” (p.14).

All of these ideas hinge around the perception that drama allows the student to move from the real world of the here and now, to another self-constructed world where feelings and meaning can be explored, reinterpreted and consolidated. Needlands (1984) argues that in everyday life we define experiences through ways that do not separate ourselves from the environment we live in, referring to this as being a vernacular form of knowing, and argues that, in schools, the message that is conveyed is that

> [l]earning through disciplines that value objectivity is more reliable, desirable and useful than learning through disciplines that combine cognition with personal, usually affective, responses (p.3).

This position, Needlands (1984) contends, is at odds with the vernacular way of learning and it would make more sense to mirror vernacular learning in classroom educational practices. There would be a need for teachers to think carefully about teaching practices they shape to enhance the role of children as active learners, rather than passive recipients of information. Needlands (1984) goes on to argue that we need to give children the opportunity to build bridges between the information that we present to them in the classroom and their own understanding. Drama, he maintains, is a tool that allows students to do just this, since it is concerned with the construction of imagined experience. Needlands (1984) contests that imagined experience is a "particularly efficient context for children to experiment with and try out new ideas, drama is to do with experiencing not performing" (p.7).

Linnell (1982) cites a sample of forty teachers saying that drama should be part of the school education system. The reasons given by those teachers for their support of the use of drama included: a perceived increase in student confidence and ability to operate as part of a group; the development of the students' imaginations and competency in self-expression through words and movement; and the reinforcement of students' concentration, critical faculty and learning by re-enacting stories and situations. In spite of these perceived advantages, Linnell (1982) also reported that only 10% (4/40) of the teachers interviewed at this time were able to state that drama was used in their school.

2.4.4 Provision of drama in schools

Pemberton-Billing and Clegg (1965) wrote of how drama had emerged as a subject in the preceding twenty years, at the same time lamenting its slow uptake in schools due to the general shortage of drama specialists. The Department of Education and Science (1968) published a report into drama provision in schools, gathering data in 1966-1967 across a sample of 46 primary schools, 62 secondary schools, 30 colleges of further education and 12 theatres. The report showed that, at that time, the uptake of drama in the curriculum was very mixed. Data in this survey showed that the proportion of schools in which drama was recognised as part of the curriculum was varied; in Northumberland, for example, whereas all 14 grammar schools had included drama as part of the, only 45 of the 68 secondary schools had done the same. There was, at the same time, an increasing level of acknowledgement on the part of the Department of Education and Science of the potential utility of drama in education (Department of Education and Science, 1968). The authors of that report into the use of drama in education noted that the instinct for play appears not to disappear in children as they grow older. The report argued instead that whilst the school curriculum may reduce the opportunities for play, the latent child in older students can be re-awakened through the use of drama. It would seem that this advice largely fell on deaf ears.

Almost a decade on from the Department of Education and Science (1968) report, McGregor (1976) reported that drama was more commonly used in comprehensive schools than it was in other types of school; drama was, he claimed, used only infrequently in grammar, secondary modern, technical or independent schools. Similarly, specialist drama teachers were more likely to be found employed in working class comprehensive and secondary modern schools. McGregor (1976) also reported that only 25% of those staff that were teaching drama were qualified to do so, with English teachers frequently taking on a secondary role as drama teacher. Only 8% of schools were found by McGregor (1976) to have had drama as a timetabled subject, with it being compulsory for students in the first two years and then optional in upper school. At that time, only 31% of schools providing post-16 education offered any form of post-16 drama courses (McGregor, 1976). It appears, from this information, that the provision of drama as a subject in its own right was something that varied across the country.

In 1988, for the first time in England, Wales and Northern Ireland, a National Curriculum was introduced for all state schools (Education Reform Act, 1988). This National Curriculum prescribed the content of the school’s own curriculum and aimed to ensure that each student was given the same level of access to subjects throughout their compulsory education. Drama, as a subset of English, was included within the National Curriculum as something that students were entitled to experience and have access to. Along with the new curriculum, GCSE examinations for 16-year olds were also introduced and, included amongst those, was GCSE Drama.

Following the introduction of the new National Curriculum, the Department for Education and Science produced a document in which they listed the aims and objectives for the use of drama (Department for Education and Science, 1989). These aims and objectives included expectations for students at the ages of both 11 and 16. In terms of knowledge development, the document refers to students being able to extend their own personal knowledge by drawing upon their own experiences, appropriate source materials, and also knowledge about drama and theatre as cultural and historical phenomena. The document also refers both to the uncertainty of the knowledge that may be developed, due to its being partially dependent upon the direction that any drama may take during a lesson, and also to knowledge of drama as being an artistic and educational process. Nowhere in the document, though, is there any reference to the use of drama for factual content learning. However, in the concluding paragraphs of the document, there is an acknowledgement of the fact that the boundaries of drama are wide, with dramatic methods also being suitable for use in the teaching of other subjects, particularly languages, the humanities and the arts; there is, though, no mention of its application in science education.

Following the introduction of the National Curriculum, Needlands (1992) described drama as being a medium that facilitates learning through talking. He presents drama as being a practical activity that is a form of shared cultural activity where learners take on roles and adopt different viewpoints in ‘real’ experiences. Drama, Needlands (1992) argues, allows students to generate vocal and bodily responses to various constructed scenarios and allows the imagination to construct its own narrative.

Winston (2004) proposes that drama is liberating. He argues that it allows the individual to escape the confines of everyday life and to behave in a manner that may, for them, be atypical; as a result, those engaging in drama can experience a different viewpoint. Winston (2004) also argues that good drama creates vividly imagined fictional contexts that seem both purposeful and fun. Good drama, as Winston (2004) sees it, allows students to explore complex issues through the use of concrete rather than abstract ideas; this is something that could potentially be of use in developing subject-specific vocabulary. The work of Fleming, Merrell and Tymms (2004) seems to likewise support the use of drama as a means by which to improve the level of literacy in primary school students. The studies of Needlands (1992), Winston (2004) and Fleming, Merrell and Tymms (2004) all seem to indicate that drama has a role in the development of students' thinking and understanding across a range of different subjects, and that it functions using strategies not routinely employed elsewhere within the school curriculum.

More recently, the KS4 National Curriculum (2007) for English encouraged students to use ‘’inventive approaches to making meaning, taking risks, playing with language and using it to create new effects’’ (p.62) (Department for Education, 2007).

The current KS4 English National curriculum, in the speaking section, has the statement that students should be taught “improvising, rehearsing and performing play scripts and poetry in order to generate language and discuss language use and meaning, using role, intonation, tone, volume, mood, silence, stillness and action to add impact” (Department for Education, 2014a, p.7).

As a compulsory subset of the English curriculum, drama has at last found its place in the curriculum. This ensures that *all* secondary school students are entitled to learn about and practice dramatic techniques. With such experiences in the English or Drama department of a school might it be possible to use these experiences within other subject areas?

2.4.5 Drama across the curriculum

Two iterations of the National Curriculum for science include statements relating to the use of modelling and creative thought as follows:

> Experimentation and modelling are used to develop and evaluate explanations, encouraging critical and creative thought (DfS, 2007, p.207).
>
> They [students] should be encouraged to relate scientific explanations to phenomena in the world around them and start to use modelling and abstract ideas to develop and evaluate explanations (DfS, 2013, p.3).

These statements could be seen to legitimise the use of drama as a tool for scientific modelling in the science classroom.

Russell and Zembylas (2007) queried the role of the arts in cross-curricular teaching; specifically, they questioned whether arts subjects, such as drama, are disciplines in their own right or “handmaidens” (p.288) to other subjects. That line of inquiry raises the issue as to what becomes of drama, or other arts subjects, when utilised in alternative curriculum areas. This question was explored in earlier work undertaken by Bresler (1995) wherein the different manners in which drama is utilised across the broader curriculum are referred to in terms of four different forms, subservient, co-equal, affective and social integration. Bresler (1995) discusses how the subservient style uses the arts, including drama, as a tool to enhance learning in a particular subject. The performance of the drama itself is, in this case, secondary to the learning of content from the subject’s curriculum and so may therefore be considered simply as a tokenistic experience involving no reflection on the part of the students about the dramatic processes they have been utilising. In the co-equal cognitive interaction style, when drama is employed in the lesson it is accorded the same level of importance as the curricular content of the subject being taught. The affective style of cross-curricular activities involves student engagement with drama in order to explore meaning in a creative way. The final style, social integration, involves the use of drama across the curriculum to celebrate cultural diversity. If drama is to be used within science lessons then the teacher will need to have considered all of these approaches and potential issues when planning them.

More recently, new evidence of drama being used across a range of curriculum areas has emerged. The literature provides examples of drama being used in mathematics (Fleming, Merrell and Tymms, 2004; Erdogan, 2008), history (Otten, Stigler and Woodward, 2004) and science. Within the sciences there are a number of examples of drama being used in the teaching and learning of both scientific concepts (McGregor, 2012) and aspects of the How Science Works/Working Scientifically sections of the curriculum (Phillipson and Poad, 2010, McGregor, 2017).

2.4.6 Summary of historical overview

What has become apparent from the sections above is that the use of drama in education is not uniform. Early use of drama in schools focused on its use for theatrical school productions performed before an audience that often comprised family and friends. This mode of theatrical production in schools is still widespread. Finlay-Johnson, in the early 1900s, pioneered methods through which drama could be utilised in order to help students develop knowledge and understanding across a range of subject areas. This appears to have been an unusual approach at that period in history. As the twentieth century unfolded, drama was been used to explore attitudes and feelings, both from a personal standpoint and also ‘in the shoes of another’ using student improvisation. Drama was also used to develop the ‘factual’ content of dramatic techniques and to develop ‘appropriate’ speech patterns. With the introduction of the National Curriculum for England and Wales there also arose a new imperative for all students to engage with and study drama during their time at school. Although drama has remained something that is taught mainly within the domain of English departments there have also been limited forays across the wider curriculum. The use of drama across different curriculum areas has been mainly restricted to the arts and social sciences and the learning of foreign languages. There are a number of examples of using drama to explore scientific ideas, both societal and, to a lesser degree, exploring scientific content. What follows in the next section is a review of the use of drama specifically in science education.

2.5 The use of drama in science education

In Section 2.3 the aspect of chemistry that will be focused upon in this study was identified, and in section 2.4 an outline was provided of the position of drama within the curriculum and the range of potential uses that it offers. This current section will now focus on the ways in which drama has been used in teaching and learning in the sciences. The existing literature relating specifically to the teaching of organic chemistry to those taking the subject in school post-16 is, however, notably limited. Acknowledging that that area of the field is currently under-researched, in this section of the chapter examples are cited from across all three science subjects in order to demonstrate both how drama has been utilised in science education more generally and also how this informed the design of this study.

At face value, it may seem strange to consider the use of drama-based pedagogies in science education since, as we have seen above, drama has been traditionally rooted in the humanities subjects of the school and college curricula. However, science, Lemke (1990) argues, is both anti-authoritarian and rational; as Lemke sees it, science also relies upon creativity and imagination (consider the creativity of Kekulé on dreaming about a ring of snakes leading to him proposing a structure for the benzene ring, or Watson and Crick's leap of imagination in envisaging the structure of DNA). In light of this, Lemke (1990) went on to argue that it is almost paradoxical that much science teaching consists of transmission of knowledge from teacher to student: such teaching affording little opportunity for students to access the creative component of scientific thinking, whereas for students to develop as scientists they need to be critical, curious and able to reflect upon science and scientific activity. In this respect, Lemke (1990) is also in concurrence with a statement made more recently in the 2007 KS3 National Curriculum for science (Qualifications and Curriculum Authority, 2007):

> The study of science fires pupils' curiosity about the phenomena of the world around them and offers opportunities to find explanations. It engages learners at many levels, linking direct practical experience with scientific ideas. Experimentation and modelling are used to develop and evaluate explanations, encouraging critical and creative thought (p.207).

Lemke (1990) goes on to question whether drama could provide an environment for students to engage in scientific thinking in a creative way. This view of the scientist as being a creative thinker is also supported by Shanhan (2009) who maintains that to not countenance the use of creative activities in the science classroom is to portray an inaccurate picture of what a scientist does and how they think. Lemke (1990) further reasons that this perceived lack of creativity and imagination in science may influence student choices as they move up into secondary education and beyond, potentially influencing them to decide not to study science further than is necessary.

A review of the literature reveals that there are a number of interesting examples of use of drama across the sciences, including instances in which drama has been used to educate trainee science teachers (Karakas, 2012; Braund, 1999). It would seem that the most widespread use of drama occurs in primary school (students age 4-10) although there are also examples of its use in secondary school. McGregor and Precious (2012), working with Key Stage 1 school students, defined dramatic science as being

> [a]n approach to teaching science that purposely places the children in thought-provoking situations where they need to apply their scientific understanding to decide how to act (p.10).

Drama in the science classroom can focus on historical aspects of science, for example, the Lord Kelvin and the Age of the Earth debate (Stinner and Teichmann, 2003), or else upon societal issues and science, such as the use of genetic testing (Dawson et al., 2009). The use of drama in the exploration of societal issues is often to be found to have taken place in the context of biology lessons. A third area in which drama has been employed in science education is in the development of conceptual understanding of scientific concepts such as particle behaviour in gases (Moore, 1992) or the formation of atomic bonds (Hibbitt, 2010). One publication providing a comprehensive set of classroom materials for use with primary school children has been produced by McGregor and Precious (2014) and is based on earlier research by McGregor (2012). Another publication, provides a wide range of classroom resources to be used across the three sciences with students aged 11-16 (Abrahams and Braund, 2012).

Many publications aimed at the classroom teacher adopt a rhetorical approach of ‘come and try’ whilst presenting little evidence to support claims as to the effectiveness of the strategies they advocate. Dorion (2009) and Ødergaard (2003) both note the lack of research carried out in the area of the use of drama in science education, the latter stating that “the field of drama in science education is neither highly theorised nor highly researched” (p.76).

2.5.1 Drama in teaching societal and historical aspects of science education

Dawson et al. (2009) looked at the use of drama in the context of learning about genetic testing; the drama was designed to stimulate discussion about social issues. In that study, a total of 240 students, aged 16-19, took part in small group discussion workshops following an open-ended drama presentation. Students in these groups then worked to formulate answers in response to questions concerning genetic testing. The authors claimed there was an increase in the level of student comprehension, as documented by the use of scientifically appropriate use of language and concepts; this claim was based upon noted changes in the use of scientific language in mind maps, and it did not use statistical analysis. Further to that, Dawson et al. (2009) also state that students supported each other during the group work, and in doing so they combined their knowledge in order to develop understanding of concepts. This, Dawson et al. (2009) propose, was able to occur because students built upon the answers and ideas given by other students within the group earlier in the discussion. Students also referred to their own personal experiences in order to make sense of the new set of circumstances presented for discussion. Wertsch (1993) argues that the use of personal experience to assist in making sense of something new or challenging, through a process of reflection and integration into the new context, allows students to contribute to group discussions and help to support the construction of new meaning. This appears to highlight the value of discussion in constructing meaning. This can arguably be gained through a variety of teaching strategies, but drama provides a natural forum for such discussions.

Students are able to access ideas central to the drama through taking on the identity of characters during their discussions (similar to the work of Heathcote and the ‘mantle of the expert’). May (1998) talks of how “story schemas” (p.401) allow individuals to produce a personalised narrative that can be recalled at a later date while Gamble and Hunter (1999) claim that girls respond better than boys to the use of narrative and storytelling, whilst boys tend to prefer factual, direct language. It has been claimed that the use of drama with students aged 10-11, such as the scripting and performance of talk show narratives in which students assume the roles of interviewees on the Oprah Winfrey show, increases student motivation (Moore,1992).

Reflecting on the use of scripted drama for historical events pertinent to science education, Begoray and Stinner (2005), postulate that this methodology of using realistic drama scripts can also be used to promote learning in science; they argue that by making the scripts authentic and personalised they allow students to access the scientific ideas in a way that might not have been possible otherwise. This form of drama allows the learner, as Metcalfe et al. (1984)

contended, to “take on the role of another, to cast off the egocentric perspective” (p.78). Begoray and Stinner (2005) did not provide data to support a claim of there having been an improvement in students’ understanding of science, but they did present a rationale for drama being held to be a useful pedagogical tool in the science classroom. In other words, drama allows the student to broaden their view and see an issue from different perspectives, (see Section 2.4.3 relating to the work of Boal and Heathcote, where this is proposed as a benefit of using drama as a teaching and learning tool). In instances when drama is used to develop an understanding of science in the context of society, scientific concepts often give way to personal experiences with emphasis on the affective domain, for example, empathy with players in the drama (Duveen and Solomon, 1994).

2.5.2 Learning scientific content through the use of drama in science education

Bailey and Watson (1998) evaluated a dramatic model that had been designed to represent an ecosystem, with primary school students taking on the roles of different components of that ecosystem. They claim that students enhanced their emotional involvement in the development of mental models of living systems. This approach to teaching led to claims that it had also allowed students to further their understanding of the relevant scientific concepts. These claims were based upon a direct comparison of test scores without any statistical analysis, and with only a limited controlling of variables. A later study by Hendrix, Eick and Shannon (2012) worked with primary school children on the topics of sound and solar energy using drama as part of the classroom pedagogy in an enquiry-based science programme. In cognitive tests, students in the group using drama outperformed, to a statistically significant degree, the group that did not use drama in the classroom.

It has been claimed that by making experiences of drama exciting and enjoyable they are also made more memorable (Christofi and Davies,1991). They claimed that while over 70% of students were enthusiastic about using drama, less than 50% of all teachers used drama techniques, with that percentage being even lower in secondary schools. In other words, even though students wanted to use drama in their learning, they did not get as many of these experiences as they might have liked.

As seen in Section 2.1.5 above, one of the challenges met within science education is how to assist students in the use of specific scientific vocabulary (Wellington and Osbourne, 2010). Fels and Meyer (1997) describe how it is often the case that when trainee teachers employ drama in their lessons they revert from the use of scientific terminology back to vernacular vocabulary in order to interpret their understanding of scientific concepts, and this deepens their understanding. Wagner (2007) describes how students need to use vernacular language at least in the initial stages of developing understanding in order to support further exploration of scientific meaning and to provide a bridge to the new scientific language. Through the use of mind maps constructed by students, aged 16-19, in biology lessons, Dawson et al. (2009) were able to demonstrate there was in improvement of the use of scientifically correct language following use of drama and discussion in science lessons.

In one study, Braund (1999) presented findings drawn from a study in which 37 trainee primary teachers used drama to explore and develop their understanding of circuit electricity, generation of electricity and electricity supply. After having engaged in a range of related laboratory practical work, groups of trainees were given information pertaining to a number of dramatic techniques that they could make use of; they were then left to develop their own drama productions. Working in their groups, the trainees presented their drama and then indicated how successful they perceived the drama to have been in contributing to their learning of scientific principles. Of those trainees involved in the study, 95% felt that their understanding had been developed and strengthened as a result of drama having been used, and 49% of those also reported that they felt those gains to have been either “major” or “significant” (p.4). It should be noted, however, that no statistical analysis was performed on those data sets. Braund (1999) also reported, further to that, that participants in the study felt they were able to learn from watching the presentations of other groups as well as by performing their own dramas.

The work of a team including twenty primary school teachers from across ten different schools was reported in a study carried out by McGregor (2012). Over the period of a year, the teachers were trained in the use of a range of drama techniques and they then took these into their schools, working with students aged 5-7 in science lessons. The drama techniques became embedded in classroom practice over this time and were used as part of a thematic curriculum, including themes of 'exploration' and 'the Olympic games', that were used to contextualise student learning. The study demonstrated, through the use of questionnaires, that 92% of students felt the use of drama in their lessons helped them to understand more difficult ideas in science, whilst teachers consistently reported that they considered students to have learned scientific content more effectively using this pedagogy than other methods they had previously utilised.

Investigating the possible benefits of observing drama in science lessons, Peleg and Baram-Tsabari (2011) worked with 288 students from two different age groups (7-8 years and 10-11 years) who watched a scripted play about the nature of matter, with the drama covering ideas such as the particle model, mass and density. Analysing answers that those students gave in questionnaires that included subject knowledge assessment items and semi-structured interviews, Peleg and Baram-Tsabari (2011) noted that, overall there was a statistically significant improvement in test answers for all groups, which indicated that learning of scientific content had taken place from watching the play. Ten months after the play had been observed, however, the level of knowledge retention had decreased notably from what it had been immediately after the performance. There were also differences in the scores that reflected the age and gender of the students: girls appeared to achieve a greater average increase in their scores than boys, whilst younger children made more gains than older ones. It was also reported by Peleg and Baram-Tsabari (2011) that when students were able to recall knowledge, they often linked this to examples from the play. There was, however, no statistically significant improvement in answers to a question that required the transfer of newly acquired knowledge into novel contexts (Peleg and Baram-Tsabari, 2011). This indicates that watching the production had promoted that which Marton and Saljo (1976) referred to as surface learning. It should also be noted that the study reported by Peleg and Baram-Tsabari (2011) had no control group against which to compare subject knowledge gains.

Bailey and Watson (1998) carried out research that showed that an increase in scientific knowledge was greater, to a statistically significant degree, in a group of students who had been taught using drama than it was in a group who had experienced traditional methods of teaching the same scientific content. Using a sample of 98 students in Year 6 (aged 10), the study involved half of the students taking part in a two-hour intervention role-play, whilst the other half became the control group, and spent a similar amount of time being taught about habitats and the exchange of matter and energy within the environment. Learning objectives for the lessons were clearly identified and assessment items were designed to assess students' ability to recall, analyse and evaluate. Overall scores for students taking part in the role-play were 47% higher than those not involved in the role-play, with the lowest score from the role-play group also being greater than the highest score from the control group. Scores from the two groups were judged to be different at the level $p < 0.001$ of significance, with those using role-play performing significantly better than the group being taught using traditional methods. Although the students involved in the study carried out by Bailey and Watson (1998) were significantly younger than those that are the focus of this current research, it is of interest as an example of a quasi-experimental study aimed at examining the impact of drama on student subject knowledge in the sciences.

Abed (2016) conducted research in the Jordanian education system with 13-year-old students. One class of 46 students learned about heat using drama whilst the control group of 41 students were taught the same content using traditional methods. The drama group were guided by their teacher to act as particles, using their bodies to mime the behaviour of atoms and molecules at different temperatures. Analysis of subject knowledge showed a statistically significant increase in the scientific knowledge evidenced by students in the drama group, an increase that was greater than that seen in the control group.

Arieli (2007) worked on the topic of mixtures and solutions in three schools in Israel with 130 students, aged 11-12. Following a teacher-led introduction of the scientific content, the intervention group wrote and performed their own skits or plays over the course of one lesson while the control group lesson followed the existing teaching schemes employed in the school. Statistical analysis of pre- and post-test responses concluded that the drama group performed better than the control group to a statistically significant degree ($p < 0.001$). In subsequent interviews, students and teachers also indicated that they thought that the use of drama helped learning of difficult topics.

It has been suggested, on the other hand, by both Metcalfe et al. (1984) and Ødergaard (2003), that the use of drama in science education does not necessarily improve levels of scientific factual recall above that displayed by control groups not using drama. However, Metcalfe et al. (1984) do also claim in their study that the ability to achieve deeper understandings of scientific ideas is significantly increased through the use of drama, with students being found to be able to provide explanations and interpretations at a higher level following the drama intervention than were those who had been in the control group. In their study, Metcalfe et al. (1984) worked with 47 students, age 10-11, and drama was used in the intervention group in order to explore students' understanding of changes of state. The control group in the study, by contrast, spent the same amount of time as the intervention group learning about the key scientific concepts using other teaching methods. Key learning objectives were agreed upon and were common to both groups. Analysis carried out after the intervention revealed there were no statistically significant differences between the mean scores of the two groups for answers given to factual recall questions. In the explanation and interpretation questions, however, the students in the drama group were found to have achieved scores significantly higher than those attained by the students in the control group. Metcalfe et al. (1984) claimed that deeper levels of understanding are enhanced through the use of drama; this links once again to the model of deep and surface learning proposed by Marton and Saljo (1976). As used by Marton and Saljo (1976), surface learning relates to the ability to recall facts (akin to lower levels of Bloom's (1965) taxonomy) whereas deep learning is related to the ability to explain and evaluate information and data (as is also described in Bloom's (1965) taxonomy for the cognitive domain).

Hattie (2008) reviewed some 800 articles and reported effect sizes for 138 influences related to learning outcomes, ranking them by effect size (given by Cohen's *d*, the standardised mean difference between groups). The average effect size was found to be +0.4 with an effect size of +0.2 being due to normal maturation processes.

Table 2.4 Effect size values for selected influence related to learning outcomes, based on Hattie (2008)

Influences	**Effect size (Cohen's d)**
Small group learning	+0.47
Creativity programs	+0.62
Drama/arts programs	+0.38
Cooperative vs individualistic working	+0.55
Practice testing	+0.54

All of the influences in Table 2.4 are relevant to the use of drama in the classroom, and their effect sizes all fall within the range that Hattie describes as being likely to have a positive impact on student achievement.

2.6 Learning

Earlier in this chapter, claims that the use of drama in science education can bring about different types and levels of learning have been reported. In this section, an overview is provided as to what it is that learning can be understood to be, as well as of the ways in which learning has been classified into different types.

2.6.1 What is learning?

Illeris (2007) defines learning as being “any process that in living organisms leads to permanent capacity change and which is not due solely to biological maturation or ageing” (p.3).

This broad definition will serve in this thesis, since it encompasses a range of factors that can be seen to have a potential impact upon an understanding of learning, including those that are pertinent to this study. Illeris (2018) also goes further in defining learning, describing it as an internal process that occurs in response to the individual learner’s interaction with the external environment and arguing that these interactions need to be incentivised; in doing so, reference is also made to “mental energy that runs the process” (p.3). According to this model, interaction between the individual and external environment leads to learning if there is appropriate incentive to allow acquisition to take place. The relationships between content (knowledge and skills), incentive (mental energy necessary for the learning process to take place) and environment are identified as fundamental to the processes in learning (Illeris, 2018). These relationships can be seen in Figure 2.12.

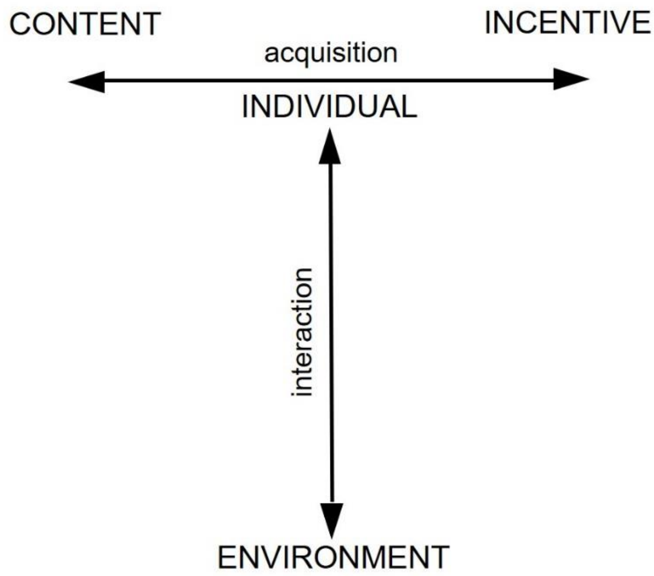


Figure 2.12 The fundamental process of learning, Contemporary theories of learning (Illeris, 2018, p.3)

Expanding upon these ideas led Illeris (2018) to construct a model of the three dimensions of learning and competence development as seen in Figure 2.13 below.

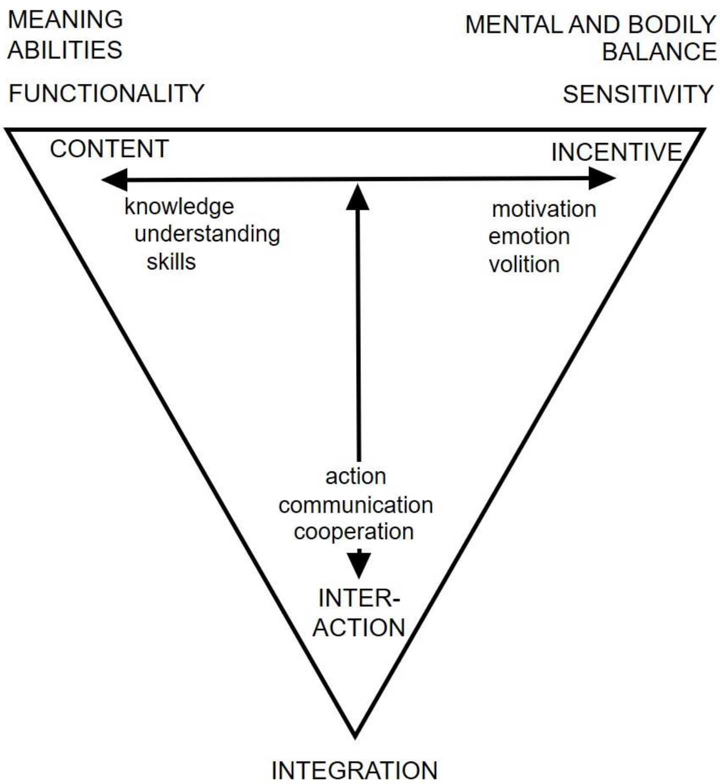


Figure 2.13 The three dimensions of learning and competence development (Illeris, 2018, p.4)

Here the links between the three dimensions of learning are made clear. Knowledge, skills and understanding (CONTENT) are the desired outcomes in a specific educational setting: the recollection and understanding of organic reaction mechanisms in an A Level chemistry class, for example. Motivation, emotion and volition (INCENTIVE) in combination with action, communication and cooperation (INTERACTION) lead to learning with the desired content outcomes. Figure 2.13 indicates the presence of dependent links between the three dimensions of learning and competence development. In an educational context, the focus is often placed upon the learning content, i.e. the declared learning goals for a lesson. However, using this model shown in Figure 2.13, it can be seen that incentive and interaction are both dimensions that also play an important role in the development of the desired content. If a learner is neither interested nor motivated to engage with their learning then the desired learning may not take place to full effect. Implicit within the integration process are the classroom pedagogies utilised in lessons. For the purposes of this study the use of drama is the relevant classroom pedagogy, and the one that is to be examined. Illeris (2018) emphasises that each of the three dimensions referred to in Figure 2.13 has a mental as well as a physical aspect, a claim that echoes the work of Piaget (1964) whose theories of child development describe how learning begins with the body, develops in the brain, and gradually takes the form of something that is mental whilst equally never totally independent of the body.

Hattie and Donoghue‘s (2018) model of learning states that learning consists of three components: learner inputs, learning outcomes and learning agents. They sub-categorise two of those components, learner inputs and learning outcomes, into the following three dimensions: skills, a student’s pre-existing knowledge and abilities; wills, a student’s disposition that might have an effect upon learning; and thrills, which relate to motivation, emotions and enjoyment of learning. The third of the major components, learning agents, are understood to be the phenomena that facilitate learning and these include, significantly for this thesis, pedagogical interventions.

Engström (2018) considers the factors contributing to learning in a manner that offers a few useful parallels with the research presented in this thesis. In their paper, Engström (2018) presents a model wherein a range of factors that are needed to produce meaning are considered. The learner is influenced by a range of individual and group actions and interactions to produce what Engström (2018) calls a “human activity system” (p.48). He argues that it is this complex social interplay that results in individuals constructing their own meaning. The activities, group interplay and classroom pedagogies together all play a part in providing mediating influences to promote the construction of meaning in the desired context.

The models above all propose that the learner and external environment interact to produce a learning outcome wherein the learner has constructed their own meaning. Piaget (1964) clearly differentiates between development and learning, stating that the development of knowledge is a spontaneous process, that is linked to embryogenesis, a term denoting the development of the nervous system and mental function that is holistic and continues through a person's life. Learning, on the other hand, he proposes is provoked, typically by a teacher with respect to a specific didactic point.

2.6.2 Types of learning

Kegan (2018) classifies learning into two types, informative and transformational. Informative learning refers to changes in *what* we know, e.g. being able to recall the definition of a nucleophile, while transformational learning refers to changes in *how* we know, e.g. questioning how the charge on a nucleophile arises. Kegan (2018) describes informative learning as “working within the frame” (p.36) while transformational learning is “reconstructing the frame” (p.36). Kegan (2018) notes that neither way of learning is better than the other, merely that they are different.

There are clear parallels to be drawn between Kegan's (2018) thinking and Piaget's (1964) models of assimilation, in which an existing schema is used to deal with a new object or situation, and accommodation, in which an existing schema cannot be used to make sense of an object or situation. In the case of Piaget's (1964) model of accommodation, the schema involved has to undergo a process of modification and restructuring and, as such, has similarities with the idea of transformational learning proposed by Kegan (2018). The model of assimilation that Piaget (1964) sets out, however, is more akin to the notion of informative learning.

Hattie and Donoghue (2018) have also proposed the classification of learning into two categories: surface learning, "factual and content" (p.98), and deep learning, "integrated and relational" (p.98). They divide both surface and deep learning into two phases: acquisition and consolidation. The acquisition phase for both denote the period in which a learner first meets or acquires new learning (surface learning) which can subsequently become integrated, networked, consolidated learning (deep learning). They also identify that learning can be extended to new situations and call this the transfer stage of learning. The relationship between these stages can be seen in Figure 2.14.

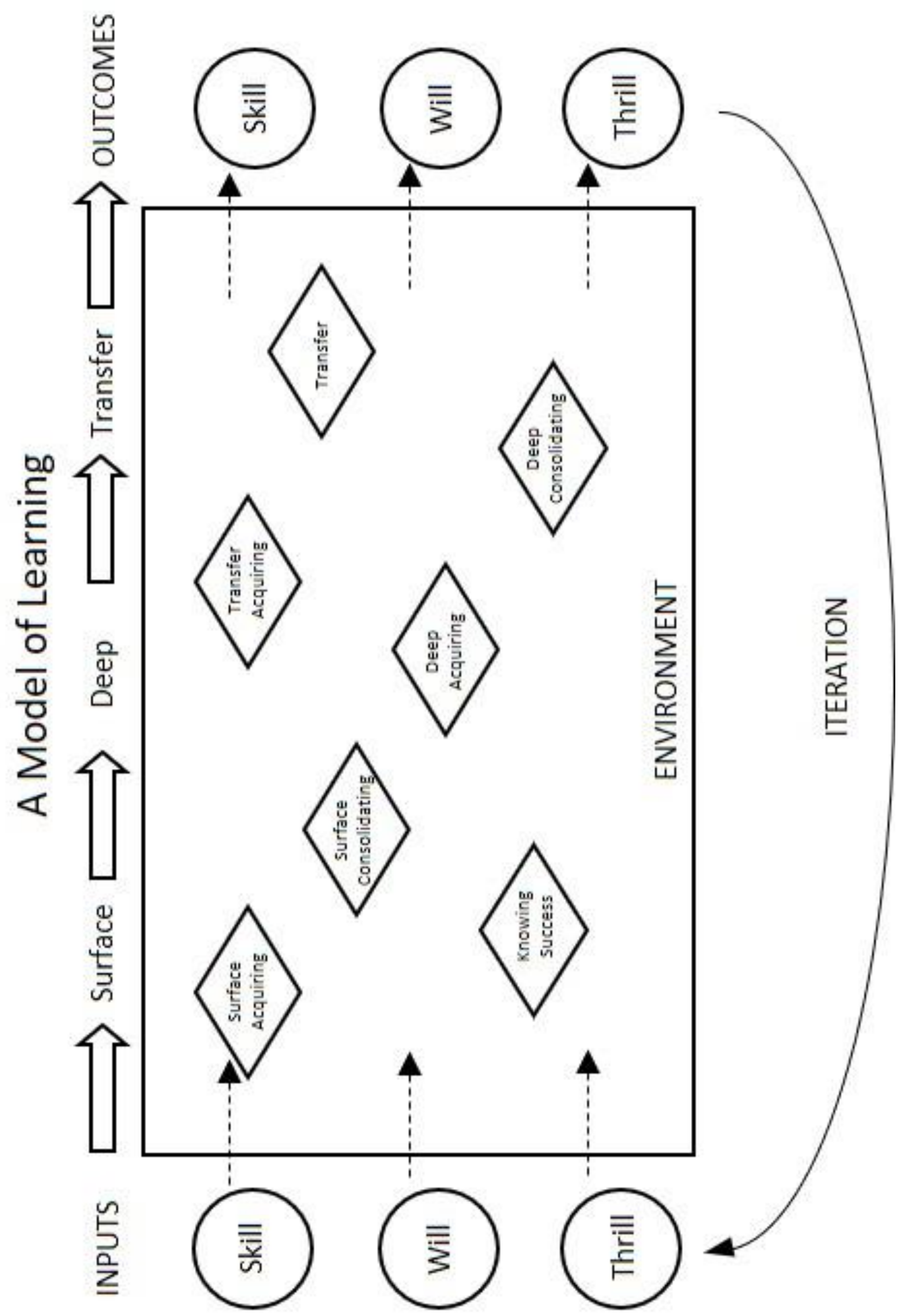


Figure 2.14 A model of learning. Contemporary theories of learning (Hattie and Donoghue, 2018, p.101)

Taber (2013) has written about the differences between novice and expert learners in the field of chemistry. Figure 2.15 shows his three ideal types of learning and, in doing so, it essentially proposes nothing markedly different from the ideas already presented above. Where Taber (2013) does differ, however, is that he postulates that, in reality, most learning is not ideal, as is represented by any area within the triangle perimeter in Figure 2.15 below. To enable meaningful learning to take place, Taber (2013) advocates the use of scaffolding: through the provision of cues, hints and modelling, the learner can be supported in their mastering of a task and becoming an expert. As the extent of a student's mastery increases, the level of support provided to them can be gradually withdrawn. The scaffolding mechanism has acted as a bridge to facilitate understanding. For chemists, the attainment of this mastery will involve moving from rote learning to the generation of a stable schema to incorporate new material. For a competent chemist, this will include the ability to make links between the visible and the theoretical models and representations of the same topic; the macro, sub-micro and symbolic levels of Johnstone's (1991) triangle.

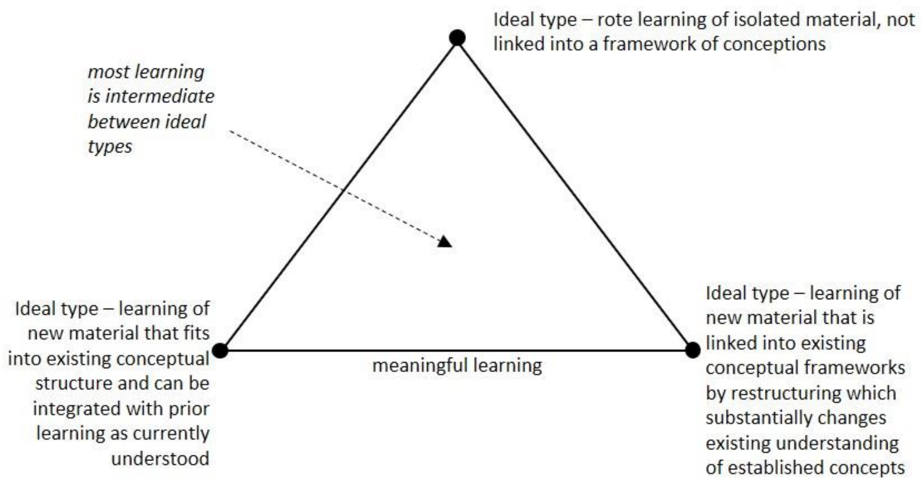


Figure 2.15 Ideal forms of learning (Taber, 2013, p.163)

Taber (2013) outlines the implications of the mastery that he proposes by discussing different responses to, and engagements with, an exemplar equation:

$$H_2SO_4(aq) + 2NaOH(aq) \longrightarrow Na_2SO_4(aq) + 2H_2O(l)$$

To an inexperienced student, this equation may appear, when first presented to them, to be simply a string of unrelated letters and numbers. A more experienced chemist, however, would conceptualise this equation in terms of a small number of items to be held within the working memory. Their internal schema might then prompt the recollection of images of titrations in the laboratory, neutralisation, the phrase ‘acid plus alkali gives salt plus water’; this internal schema might also include mental spaces into which the names of the reactants and products in the equation can be added. Such internal schemas are embedded in the three dimensions set out in Johnstone’s (1991) triangle. To assist the student in moving from novice to expert appropriate scaffolding required: it is first provided and then gradually removed as it becomes no longer necessary.

Tregaust (2003), as seen in Figure 2.6, describes how instrumental, surface learning of chemistry is a result of unconnected, discrete mental representations of Johnstone’s (1991) triangle while relational, deep, understanding is the result of a mental integration of the three aspects of Johnstone’s (1991) triangle. In order to facilitate transition from the surface to deep learning the interconnectedness of levels of Johnstone’s triangle need to be promoted through the interaction of the student with their classroom environment.

2.7 Drama in the science classroom

In order to be able to appreciate how drama-based science activities operate in the classroom it is useful to look at the work of Ødergaard (2003) who draws on Brown and Pleydell (1999) to represent the forms of organisation in such activities. Ødergaard (2003) considers two continuums that are presented in Figure 2.16 below: one that ranges between spontaneous to structured, and another one that exists from student-directed to teacher-directed on the other.

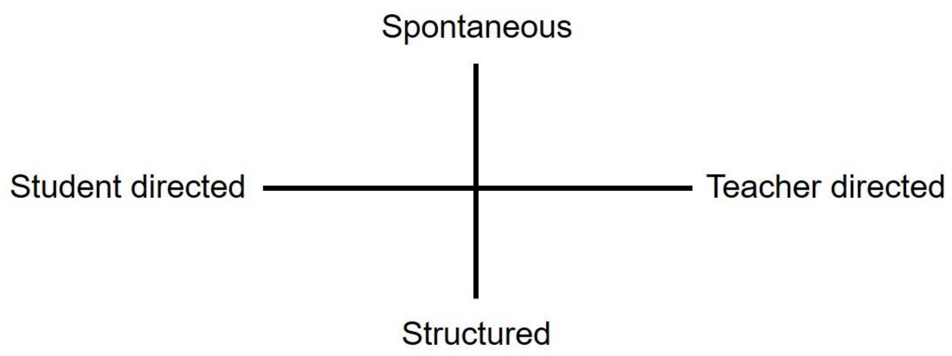


Figure 2.16 Forms of organisation in ‘dramatic scene’ activities (Ødergaard, 2003, p.79)

Ødergaard (2003) argues that presentational drama is used to inform an audience whilst experiential drama is used to “live through an aspect of some experience and adopting a motivation, opinion or attitude” (p.79). They further argue that, irrespective of the mode of drama, students are always reworking and reconstructing (or constructing) meaning from their experiences. Linking the two forms of drama referred to by Ødergaard (2003), in an earlier study Sutton (1996) argued that the production or interpretation of a script is used to assist in helping students consolidate their learning.

In order to exemplify the types of activity, as they appear in the classroom, it is useful to look at the categorisations used by McSharry and Jones (2000), in which they divide role-play into categories as seen in Table 2.5.

Table 2.5 Categories of role-play, adapted from McSharry and Jones (2000, p.76)

Category of drama activity	Examples of drama activity
Presentations	Child performing a role Making radio or TV commentary.
Metaphorical role play	Human sculpture Mime
Analogy role play	Children acting as objects or elements of scientific theory
Simulation (moral/ethical role-play)	Organised debates Simulated meetings or court cases
Theatre in education	Outside drama companies

From the examples in Table 2.5 it can be seen that all of the above lend themselves to use in the science classroom. Metaphorical role-play and analogic role-play can be readily utilised when working with scientific concepts, whilst simulation and presentations can also be usefully adopted when teaching the ‘science in society’ aspects of the science curriculum. This is broadly in line with the divisions and uses assigned by Ødergaard (2003) in Figure 2.17 below.

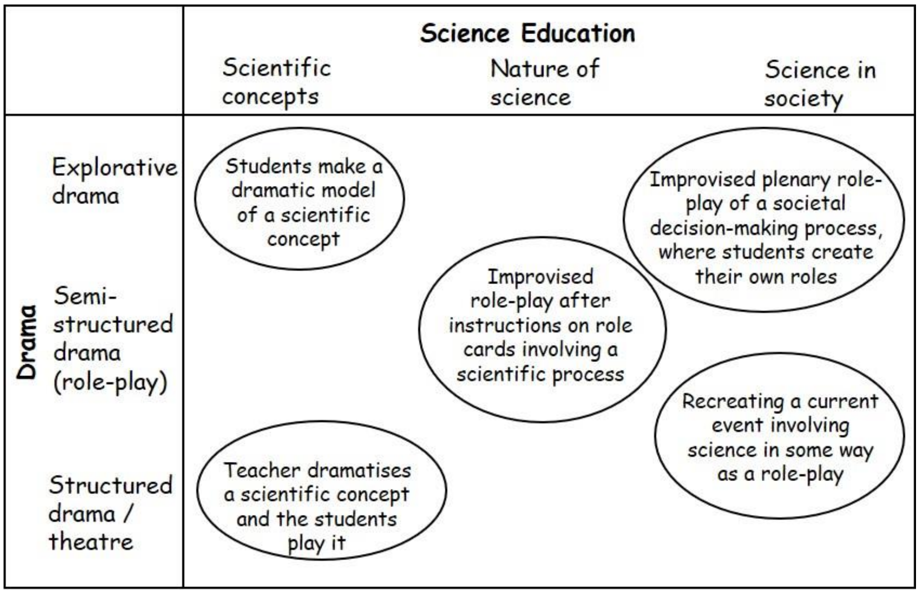


Figure 2.17 An overview of how drama might be used in science education (Ødergaard, 2003, p.81)

Dorion (2009) used an ethnographic study with five teachers talking about their experiences of using drama in the science classroom and noted that the use of role play covering aspects of science linked to "social simulations" (p.2250) was a popular pedagogy, with the potential to connect to the affective domain. An example of this type of activity was reported by Duveen and Solomon (1994) who discussed the use of historical role-play in the 'trial' of Charles Darwin. The example given by Duveen and Solomon (1994) also draws on the affective domain as it encourages the development of empathy with characters in a discussion, debate or role play.

Metcalfe et al. (1984) explored the idea of empathy and considered the possibility of adopting the role of either an animate being or an inanimate object; drama need not be seen to only have use in connection to human relationships but to also support symbolic role-play to introduce scientific concepts. Aubusson (1997) refers to this type of drama as simulation-role-play while Dorion (2009) notes that in the existing literature this type of role-play, in which the 'characters' are inanimate objects, is variously referred to by any of the following terms: "drama models, role play simulations, drama machines, analogy drama and metaphorical role play" (p.2251). Jaques (2000) notes that this type of role-play simulation allows students to manipulate representations of scale, time and space. Examples include the scale of atoms or the universe, the timescale involved in nuclear reactions or geological time, and also the ideas of vacuum and close-packing in crystalline structures. The use of such simulation-role-play has been adopted in cases referred to in Section 2.5.2 including Metcalfe (1989); Braund (1999); Abrahams and Braund (2012); Hendrix, Eick and Shannon (2012) and Abed 2016.

The chemistry content in this study is organic reaction mechanisms. This will lend itself to role play in which the participants (actors) take on the roles of the particulate entities involved in the reactions. For clarity and consistency, the term simulation-role-play (Aubusson, 1997) will be used, where appropriate, in this study.

Regarding the degree of structure, referred to by Ødergaard (2003) this will differ depending upon the phase of the study (details follow in chapter 3.) In Phases 1 and 2 the simulation-role-play will be more teacher directed and structured, in that the script and props will be provided by the researcher and Phase 3 will be more spontaneous and student directed with students writing, producing and acting their own simulation-role-play.

2.7.1 Script or no script?

Yoon (2006) considers the use of drama in science in terms of whether or not performances use a script; through so doing, they identify a number of different types of drama that are summarised in Table 2.6.

Table 2.6 Categories of scripted and unscripted science drama, based on Yoon (2006, p.3)

	Type	Outline
With script	Performance	Scripts are provided by the teacher; students act the script.
	Readers/theatre	Scripts are provided by the teacher; students read the scripts.
	Creation	Students write their own scripts and act them out.
Without scripts	Role-play	Teacher provides context and description of roles; students improvise and act out their roles.
	Improvisation	Teacher provides task or context; students decide the cast and improvise their drama.

There is an argument that increased autonomy, for example either through the use of improvisation rather than scripted performance or by having students write their own scripts, might lead to a greater sense of ownership and therefore greater levels of engagement (Swick, 1999). Bateson (1994) additionally proposes that increased ownership and engagement will consequentially result in enhanced learning.

In Phases 1 and 2 of the study the students will be provided with scripts for their simulation-role-play by the researcher and in Phase 3 of the study they will write their own script.

2.8 The theoretical basis for the use of drama as a classroom pedagogy in science education

This section examines the case made for the use of drama as a pedagogy in the teaching and learning of chemistry. First, the role that drama has in closing the gap between the “learner’s world of knowing” and the “science world of knowing” (Braund, 2015, p.110) is described. Second, following on from that, the role of visualisation and mental models in the promotion of learning in science is further considered. Finally, the case is made for the place of embodied learning, including simulation-role-play, in the production of mental models.

2.8.1 The case for using drama

Braund (2015) argues that although there is evidence to suggest that students studying arts subjects, including drama, demonstrate enhanced learning in other subjects, including the understanding of scientific concepts, there is a paucity of theoretical models that adequately account for the justification of the use of drama in science education.

In his paper Braund (2015) does present a general model for the learning of science that is based upon the idea that science education needs to move the learner from “the learner’s world of knowing” to “the science world of knowing” (p.110), calling the gap between the two the “experiential space” (p.110). When drama is the pedagogy linking the two ‘worlds’ he renames the experiential space as the “drama space” (Braund, 2015, p.111). This can be seen in Figure 2.18.

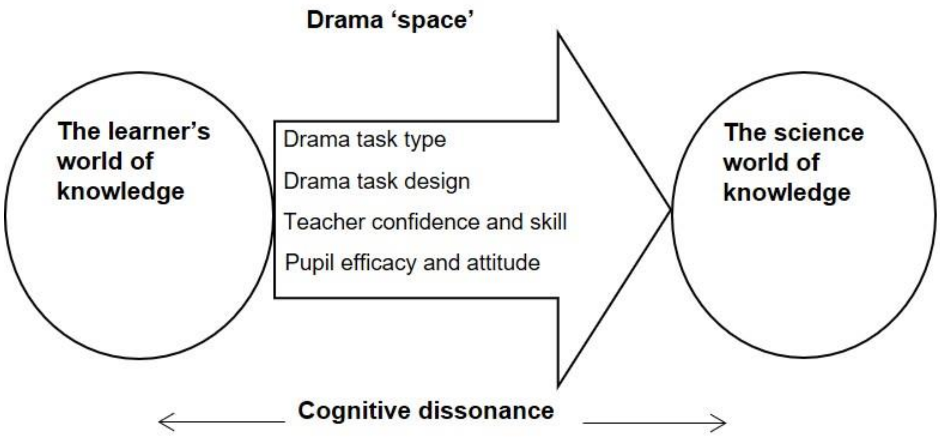


Figure 2.18 A model of learning science through drama (Braund, 2015, p.111)

It has been proposed (Dorion, 2009) that drama is a pedagogical approach that is effective in encouraging learning, as the physical role-plays can involve complex analogies; Rasmussen (2010) likewise refers to the ability of drama to transform a learner's experiences by assisting them to recognise new shapes and forms. Braund (2015) argues that it is through those transformations that the drama space presented in Figure 2.18 is filled, allowing the learner to progress and gain access to the science world of knowing. From a constructivist view point, the learner has actively engaged in building their own meaning of the relevant scientific knowledge and content through the use of bodily movement and dialogue.

What is less clear from the work of Braund (2015), however, is what it is that is actually occurring when a learner participates in drama as part of a classroom pedagogy. One answer to this can be found in the literature relating to visualisation and mental modelling; the following section will build upon some of the relevant literature in this area.

2.8.2 Visualisation and mental modelling

Gilbert (2007) considers the ways in which terminology is used in discussions concerning visualisation, a wide range of different terms often intersect and overlap. It is worthwhile, here, to briefly summarise some of those terms. Gilbert (2007) considers aspects of visualisation as starting with external stimuli. The external stimuli can be considered to be those things that exist in the world perceived as external to the learner, and these might include graphs, charts and computer animations, as suggested by Tufte (2001). Alternatively, Reisberg (1997) sub-divides visualisation into visual perception, which is the image of an object as it is perceived in the presence of that object, and visual imagery, which is the mental production of an image of an object in the absence of its physical presence. Coll (2006) refers to the metal imagery aspects as being "constructed or symbolic" models (p.68); these constructed, symbolic models may also be referred to as mental models. Cohen and Hegerty (2007) also propose that visualisations can be divided into two broad categories:

internal mental representations and external displays. The internal mental representations are described as the ability to mentally store and manipulate representations in the mind, whereas the external displays or visualisations consist of visual-spatial displays and can be either static, in the case of diagrams, graphs and equations, or dynamic, in the case of films (Hegerty and Waller, 2005). Although much of the literature on dynamic visualisations focuses on the use of computer-generated simulations and animations (Justi and Gilbert, 2002), it can be argued that drama and role-play, due to their dynamic nature whether performed or viewed by an audience, can be classified as a dynamic visualisation.

Kolari and Savander-Ranne (2004) define visualisations, in the context of engineering education, as being the formation of “a picture, a model or a scheme in the mind” (p.484). They argue that this mental modelling is crucial in the formation of links between macro, sub-micro and symbolic aspects of the world, a necessary skill for a functioning scientist. Kolari and Savander-Ranne (2004) go on to claim that scientific learning may be achieved by moving between these different levels (macro, sub-micro and symbolic) and argue that visualisation can help a learner to make these transitions. They reason this is possible because learners are actively engaged in their own learning as they construct their own internal visualisations. If that active learning pedagogy is drama, learners will be filling the “drama space” referred to by Braund (2015, p.111).

2.8.3 Scientific models and mental modelling

A model has been described as being a simplification or description of a complex phenomenon (Rouse and Morris,1986). Science is concerned with many complex phenomena that need to be simplified in order to assist student learning. This is very much the case in chemistry: there are many complexities associated with the need to move fluently between macro, sub-micro and symbolic levels that are integral to an ability to function as a proficient chemist. Gilbert (2007) discusses how models in science education can serve a wide range of content, including representations of sub-micro level particles. These models can be used to help predict the behavior of atoms, ions, molecules and electrons in a range of organic chemistry reactions and their associated mechanisms. Gilbert (2007) goes on to propose five different modes of representation for models that can be used in science education. There are three of those modes that are particularly pertinent to this study into the use of drama as a pedagogical tool for teaching and learning of organic reaction mechanisms: the verbal mode, understood as a description in language, either spoken or written; the symbolic mode, involving the use of chemical symbols, formulae and notation; and the gestural mode, which centres around the movement of the body.

As described above, in response to external visualisations, which could take the form of scientific models, students generate internal mental models. As Rapp (2007) argues these “internalised, organised, knowledge structures that are used to solve problems […] are not exact replicas of external phenomena and may be incomplete or fragmented” (p.46) and therefore the quality of a mental model will determine the level of understanding a student has of a concept. It has been argued that the incomplete mental models of many chemistry undergraduates impair their ability to make sense of the necessary mechanistic representations, thus limiting their ability to successfully produce and interpret those organic reaction mechanisms (Stricklanda, Kraft and Bhattacharyya, 2010). Rapp (2007) has noted that it is often the case that students can be seen to have passed tests merely through recollection or recognition of repetition of earlier work, without actually understanding underlying concepts. Furthermore Rapp (2007) goes on to claim that students with understanding rather than simply recall, are more able to competently tackle questions in unfamiliar contexts, and also to think critically about material above and beyond what has been presented. This links to the ideas of shallow and deep learning, theorised by Hattie and Donoghue (2018). Research by Gobert (2007) also indicates that supporting students in the use of models to understand concepts promotes deep learning of complex causal processes. Similarly, Touli, Talbi and Radid (2012) propose that the use of a range of different scientific models produce the internal mental models necessary to enhance understanding of scientific concepts, and also increase the ability to correctly apply this understanding to a range of different contexts.

Aubusson et al. (1997) promote the use of role play, not as a way of understanding the thoughts and emotions of other human beings, but rather as a way for students to play the parts of entities in phenomena in order to gain understanding about those. To differentiate between the two purposes of role-play, Aubusson et al. (1997) refer to the latter example, phenomena-based role-play, as “simulation-role-play” (p.566). Their study, involving the use of simulation-role-play to teach electric circuits in three different classes, led them to make the claim that, as a result of the lessons, students had developed their own mental models and were able to draw on these to explain the relevant physics. Aubusson et al. (1997) also claimed the simulation-role-play had enabled the students to access the scientific concepts in words and actions they were able to relate to; as a result of this, students were subsequently able to both construct meaning for phenomena that were not visible to the naked eye, and also to demonstrate the construction of deeper meaning rather than simply observational recall.

Since mental models are not themselves visible, judgements about their quality can only be inferred through inspection of their external manifestations. Gilbert, Boulter and Rutherford (2000) refer to these external representations, produced by students, as expressed mental models; these expressed mental models provide the material evidence that a researcher can use to make inferences about internal mental models. In the case of the research being presented in this thesis, the expressed mental models are found in speech, in the form of interview data, and also in the written responses to examination and diagnostic questions.

2.8.4 How might simulation-role-play contribute to the development of effective mental models?

There exists a body of literature by authors such as Lave and Wenger (1991) claiming that mathematical learning need not be an abstract process, but can instead develop as a result of student interactions with their environment, for example through the use of representations. This literature is pertinent since there are parallels to be drawn between mathematics and science education, in that they both often involve thinking about concepts and objects that are abstract and non-visible. Abrahamson (2004) documents examples of instances in which students have successfully developed their understanding of mathematical concepts through the use of spontaneous bodily gestures. Congdon et al. (2017) similarly make the case for the learning of mathematics being most effective for students when they are presented with new material in a manner that incorporates both speech and gesture, including mime. Studies by Wagner-Cooke, Duffy and Fenn (2013) and Goldin-Meadow (2014) likewise draw further attention to the notion that instruction combining speech and gesture leads to both improved retention of information and also students being able to both generalise learning to understanding of new contexts.

These ideas can be supplemented by considering the work of Alibali and Nathan (2012) who argue that "mental processes are mediated by body-based systems including body shape and movement" (p.248). This idea that the involvement of the body can have an influence upon the knowledge we build indicates that knowledge itself is embodied to an extent. Wilson and Foglia (2017) summarise embodied cognition as that which is dependent upon features of the physical body, beyond those of the brain, playing a significant causal role in cognitive processing. This is supported by the research findings of Nemirovsky and Ferarra (2009) who, following their study in mathematics classrooms, went on to conclude that immersion in imaginary scenarios via the use of embodied learning can lead to an awareness of “what could be” (p.173) in addition to what is. The implication is that embodied learning may provide a route to the point at which students are able to transfer learning to a range of different contexts and scenarios. Similar thinking has also been developed within the field of science education, with Bruun and Christiansen (2016) identifying clear links between bodily movement and the development of an understanding of certain scientific concepts, such as forces.

Hostetter and Alibali (2008) have hypothesised that since mental images reflect the spatial dimensions, and the physical and kinaesthetic properties, of the events they represent, they are dependent on the same relationships between perceptual processes that are involved in real world interactions with physical objects. This view is vindicated by the work of Ganis, Thompson and Kosslyn (2004) who reported that the act of recalling a visual mental image makes use of up to 90% of the same areas of the brain as used when viewing a materially-present object or event. Furthermore, the role of motor processes in visual mental imagery has been researched with Wohlschläger and Wohlschläger (1998) demonstrating that motor processes of the body can function to effect the recollection of visual mental images when needed to perform tasks. Wohlschläger and Wohlschläger (1998) reported that physical movements and the mental models of those movements rely upon overlapping areas of the brain. It has even been proposed that mental models are solely the product of embodiment (Glenberg,1999), the argument for this being that cognition is a result of evolution and is a necessary product of the adaptation for survival and reproductive success. The assumption is that this survival is dependent upon responses to embodied actions and that mental models must therefore have their origins in response to what is occurring in the body. This pragmatic survival argument makes a strong case for the development of mental models as being a form of embodied process. The work of Ong and Hodges (2010) provides further evidence of this, and involved the comparative study of three groups of participants under laboratory conditions. The first group (A) carried out repeated spatial awareness and tracking tasks on a screen, predicting the trajectory of a moving object by physically tracking the movements with their hand whilst being unable to see the movement of their hand. The second group (B) carried out the same task but were able to see their moving hand, and the third group (C) were unable to move their hand but could observe the movements of items on screen. Immediately following the processes described above, all three groups were required to complete the same tasks again. Initially, the participants in group C performed best in these repeated tests. However, when the tasks were transferred to different contexts, the participants in groups A and B performed significantly better than those in group C, with those who were able to see their hand movements performing best of all. Ong and Hodges (2010) hypothesised, on the basis of their findings, that observational learning alone had not led to an updating of the internal mental model to the same extent as embodied learning had done.

Whilst it is beyond the scope of this study to develop the psychological aspects further, the point of particular relevance is that there are clear and strong links to be seen between bodily movement, in this study simulation-role-play, and the production of mental models, as well as the fact that there is a corresponding connection between the development of comprehensive mental models and subsequent understanding of scientific concepts.

Chapter 3
Methodology

3.1 Theoretical influences upon research design

In Chapter 2, attention was drawn to the fact that drama, comprising simulation-role-play, has been used as a pedagogy in school science lessons, including in chemistry; these lessons have generally involved students from Key Stages 1-4 (aged 5-16) in the field of science education, as opposed to Key Stage 5 students (aged 16-18). As was shown in Chapter 2, even when the full age-range of students is considered, there is a general scarcity of statistically-analysed data available to support any claim that drama is an effective pedagogy in assisting students' understanding of scientific concepts; for students aged 16-18, however, no such claims have been made. As such, this chapter both establishes the rationale behind this study and provides a description of the methodology employed in order to answer the main research question: does the use of simulation-role-play in the teaching of organic reaction mechanisms in A Level Chemistry impact upon student learning? One intention of this study was to gather quantitative data that could then be statistically analysed in order to identify whether or not there were any statistically significant differences between the marks awarded to the control and intervention groups of students in the study. This study also aimed to gather qualitative data in order to explore students' opinions as to how useful drama had been in assisting them with their ability to recall and understand the chemistry and to answer A Level examination questions.

Hitchcock and Hughes (1989) argue that the ontological and epistemological views of a researcher will inform the research design pursued. The adoption of a particular research methodology is the result of aligning with specific philosophies of the nature of educational research (Arthur et al., 2012). Ontological assumptions about the nature or essence of the social phenomena being investigated result in what Cohen and Manion (2000) refer to as the nominalist-realist division; positions are adopted as to whether social reality is external to individuals (realist), or imposed on their consciousness from without (nominalist). Epistemological viewpoints will spring from ontological standpoints, giving rise to viewpoints that knowledge is objective and tangible or personal, subjective and unique (Cohen and Manion, 2000). The alliance with a realist, objective viewpoint lends itself to an objective approach to research in the social sciences while a nominalist, anti-positivist standpoint leads to a subjectivist approach to research in the social sciences.

Positivism, an epistemological standpoint with an adherence to the idea that true knowledge is based upon knowing that the “world and its phenomena are real and exist independently of perception” (Arthur et al., 2012, p.7), regards observations as being objective and value-free and considers knowledge to be generalisable. This approach, that holds that the universe is deterministic, lends itself to the gathering of observable quantitative data through experimentation in order to test a hypothesis (Cresswell, 2003). Positivism, however, has been described by some such as Williams and May as “one of the heroic failures of modern philosophy” (1996, p.27) as it implies that the results of research are presented as facts and established truths; this stands in contrast to the work of Popper (2005) who argued that no theory can ever be proved, merely falsified. Scholars such as Phillips and Burbules (2000) have challenged the notion of absolute truth proposed by positivism and claim instead that researchers cannot be so *positive* about assertions of knowledge when studying the behaviour and actions of humans. Accordingly, arguments such as the one made by Phillips and Burbules (2000) can be identified as being post-positivist. A summary of the outcomes of these linked, yet differing, views is neatly expressed by Trochim (2006):

> Where the positivist believed that the goal of science was to uncover the truth, the post-positivist believes that the goal of science is to hold steadily to the goal of getting it right about reality, even though we can never achieve this.

The post-positivist view still maintains many elements of positivist thought: it represents a deterministic philosophy in which causes determine outcomes; it is reductionist in nature, condensing discrete sets of ideas to testable concepts; and it relies upon observation and measurements made in a world *out there* (Creswell, 2003). Post-positivism recognises that the way in which scientists work, and the way in which we think during the course of everyday life are similar. However, one strand of post-positivism, critical realism also holds the view that there is an independent reality out there waiting to be studied and measured. The school of critical realism emerged from the writings of Bhasker (1975). Critical realists contend that there is an external reality, measurements of which constitute intransitive knowledge (in the case of this study this includes student responses to the assessment items). This positivist component of critical realism links to an ontological view that there will be fixed data out there to answer a given question. The research question do students' marks in A Level examination questions on organic reaction mechanisms differ, in a statistically significant manner, depending on whether they have been taught using simulation-role-play or practice examination-style questions? is poised to answer a unique dataset of test scores, external and intransigent, so has been constructed with the 'positivist' component of the critical realist school of thought in mind. Critical realists also believe that knowledge about what causes events in that external reality is a transitive knowledge, mediated by the cultural and theoretical world views of the participant and researcher. This is not to say the results are not valid, but that they are valid for the context in which they were made. In order to increase objectivity, post-positivists advocate the use of data triangulation and this approach leads naturally to research designs that incorporate mixed methods. The balance between the existence of the world-out-there and the resultant interplay of the data collected with the internal constructions of meaning by the observer stand as a middle ground between positivism and interpretivism. Research questions 2,3 4 are concerned with student attitudes pertaining to their experiences in the classroom. An attitude can be defined as “a psychologic tendency that is expressed by evaluating a particular entity with some degree of favor or disfavor” (Eagly and Chaiken,1993, p.1). The essence of this umbrella definition is that attitude is an individual, internally constructed phenomenon in response to events in the external world. Each attitude is unique and context specific, falling into an ontological framework of nominalism and an epistemological category of anti-positivism.

Interpretivism, as an anti-positivist stance, proposes that universal laws cannot be generalisable due to the subjective meaning of social situations being necessarily mediated by the individual and therefore unique (Bryman, 2012). Research studies that adopt such an epistemological perspective seek ideographic answers: answers that are unique and specific to the individual (Grey, 2017). Interpretivists argue that these individualised world views that inform outcomes are the result of social interactions and therefore do not exist independent of individual interpretations set within social discourses and contexts. From an interpretivist perspective, it is necessary to obtain data from individuals who are immersed in the contexts relevant to the study (Furlong and Marsh, 2002); this epistemological position provides a basis and imperative for the use of qualitative data.

It has been argued that the ontological and epistemological standpoints of a researcher are “like a skin not a sweater: they cannot be put on or taken off as the researcher sees fit” (Furlong and Marsh, 2002, p.17) and this will therefore colour and inform their research, including its design. The researcher acknowledges here that they are of a critical realist mind-set, in the school of post-positivism, and that this has influenced the research design of this study. This critical realist view lends itself to a range of data gathering styles (mixed methods) to answer the different types of research questions; quantitative data gathering to answer research question 1 relating to intransitive knowledge and qualitative data to answer the research questions 2, 3 and 4 pertaining to transitive knowledge.

3.2 Research design

The following section looks at the different approaches taken in this study in order to justify the choices made and to give a brief outline of the initial research design. Detailed explanation of how these approaches were operationalised can be found later, in Sections 3.3 and 3.4.

3.2.1 Mixed methods research design

This study used a mixed methods approach, utilising both qualitative and quantitative methods of data collection. The particular value of mixed methods research in educational settings has been highlighted by Teddlie and Tashakkori (2009), who observe that it increases the breadth of a study and allows questions to be asked that it would not be possible to answer through the analysis of quantitative data alone. Morse (2003) also supports the use of mixed methods, claiming that they allow a more complete picture of experiences to be obtained. It has also been argued that the convergence of findings stemming from two or more methods enables us to more readily accept the validity of results (Johnson, Onwuegbuzie and Turner, 2007).

In order to answer the first research question, do students' marks in A Level examination questions on organic reaction mechanisms differ, in a statistically significant manner, depending on whether they have been taught using simulation-role-play or practice examination-style questions?, a quasi-experimental design was used to gather quantitative data relating to whether or not the use of simulation-role-play impacted upon the marks a student obtained in assessment items. Additionally, questionnaires were used to gather background data such as prior achievement in science at GCSE and the school each student attended. This section of the design is firmly rooted in a positivist epistemological approach, with the gathering of non-negotiable test marks, and fixed student specific data, the nature of which is intransigent.

The nature of perceptions being individually constructed as a result of interaction between the individual students and their experiences in the intervention lessons gives rise to subjective, transitive ideas that can be explored. This places the ontological perspective as nominal and the epistemology to be anti-positivist or interpretivist. Opportunities are needed to allow individuals to express their diverse attitudes. To facilitate this the questionnaires gathered qualitative data relating to student attitudes towards the intervention lessons. Group interviews were also conducted with a sample of students from the drama group, yielding qualitative, illuminative data across a range of views. These strategies allow the second, third and fourth research questions below to be explored;

ii. How do students perceive the use of simulation-role-play in their recall of organic reaction mechanisms?

iii. How do students perceive the use of simulation-role-play in their understanding of organic reaction mechanisms?

iv. How do students perceive the use of simulation-role-play in preparing them for answering examination questions relating to organic reaction mechanisms?

It was initially anticipated that, following a short pilot stage, the study would continue over a period of two academic years, following the same group of students through two interventions, one in each academic year. This plan is summarised in Table 3.1.

Table 3.1 Proposed outline of the stages of the study

Stage in planned study	**Summary of student activity**	**Anticipated number of schools and colleges**
Pilot	• Practicing intervention and control lessons. • Pilot of questionnaires.	2
Stage 1	• Intervention and control lessons relating to nucleophilic substitution carried out. • Students complete assessment items and questionnaires. • Selected students take part in group discussions.	10
Stage 2	• Intervention and control lessons relating to nucleophilic addition carried out. • Students complete assessment items and questionnaires. • Selected students take part in group discussions.	10

This type of mixed methods approach conforms to what is known as “sequential explanatory design” (Cresswell, 2003, p.215). In such an approach, quantitative data is given priority, being gathered and analysed first, with qualitative methods being employed subsequent to that; the different methods are integrated during the final, interpretative phase of the study. In essence, the qualitative data is used to assist in explaining and interpreting the findings of the primary quantitative data. Often qualitative and quantitative methods can be used in conjunction so that the strengths of one offset the weaknesses of the other (Newby, 2010). In the case of this study, quantitative analysis provided data that could then be analysed to determine whether or not there was a statistically significant difference between answers to examination questions, depending upon whether students were in the drama or examination-style question group. That quantitative analysis, however, provided no insight into what student attitudes were towards either the value of simulation-role-play in helping them to remember and understand the chemistry or the usefulness of the pedagogy when it came to answering examination questions. The qualitative data, on the other hand, allowed for a greater understanding of the students' thoughts, feelings and attitudes towards the use of drama in assisting with the recall and understanding of the chemistry and answering of A Level examination questions, whilst conversely not providing any statistical evidence as to the effectiveness of drama in enabling examination questions to be answered correctly. In the use of sequential explanatory design, the different data sets are, to a greater or lesser degree, combined to tell a coherent whole. Although time-consuming, this mixed method approach is a well-tried and tested model and can help provide insights and understanding of data that might not have presented itself without the combination (Cresswell, 2003; Johnson and Christensen, 2014).

As Burns observed in his poem 'To a Mouse', "The best laid schemes o' Mice an' Men, / Gang aft agley" (Crawford and Imlah, 2001, p.282), and so there were inevitably changes made to the details of the planned design, although the broad outline was adhered to. Before looking at the revised plan in detail, there follows here an outline of the rationale for adopting the measuring instruments that were used.

3.2.2 Quasi-experimental design

The first research question asks as to whether or not students' marks in A Level examination questions on organic reaction mechanisms differ, in a statistically significant manner, depending upon whether they have been taught using simulation-role-play or practice examination-style questions. This study draws on a positivist and post-positivist rationale in order to answer that question. The underlying assumption is that manipulation of an independent variable will lead to measurable changes in the dependent variable; in this study classroom pedagogy is the input variable and student responses to assessment items is the output variable. Learning theory, as was discussed in Chapter 2, holds that external factors interact with internal aspects of the learner to produce learning outputs. Engström's (2018) model describes the output from a subject as being dependent upon a mediating input or object: for example, the understanding of an aspect of chemistry, as judged by responses to assessment items, will be influenced by the interaction of the student with pedagogical inputs in the classroom. Since the purpose of this study is to determine the effectiveness of drama in bringing about learning, as demonstrated by answers to A Level examination questions, it has been designed with intervention lessons and control lessons that use the same chemistry content. In true experimental research design, the independent variable is manipulated and participants are randomly allocated to the control and intervention groups (Kumar, 2019). In this study the participants were randomly allocated to intervention and control groups not as individual students but as entire teaching classes. In addition, this study did not adhere to the pre-test/post-test model described by Cohen and Manion (1994) as students involved would not have come across organic reaction mechanisms in their earlier chemistry studies. As a result, tests were only conducted post-intervention and so, again, as it does not meet the requirements of a true experimental research design the methodology of this study must be more accurately categorised as being what Siegle (2019) categorises as quasi-experimental.

Participants in this study were all working towards their A Level Chemistry qualification, the award of which is determined by externally-examined written assessments that are sat at the end of the two-year course. Grades awarded for A Level are totally dependent upon the marks awarded in these terminal written examination papers (Ofqual, 2015c). Previously unseen past examination questions were used as post-intervention measuring instruments to compare the performance of the control and intervention groups, and they were marked using the relevant mark schemes available from the associated examination boards. The study was designed as a series of quasi-experimental intervention lessons in which the input variable was the teaching and learning pedagogy and the output variable were the marks awarded for the answers to these examination questions (subsequently referred to as assessment items). The resultant data were presented in numerical format appropriate for quantitative statistical analysis. Such quantitative analysis can be viewed as a way of attempting to manage data in order to identify differences and correlations (Borg and Gall, 1983). Analysis allowed an insight into whether there were any statistically significant differences between the marks obtained by the intervention and control groups. Sections 3.6.1 and 3.6.2 further describe how the quantitative data were analysed and Chapter 4 presents the results of that analysis.

All participating schools and colleges were running two parallel A Level Chemistry classes. In order to reduce variation in teaching style, all of the lessons throughout the study were taught by the researcher using pre-prepared lesson plans. Post-intervention assessment items, taken from past papers written by each of the three examination boards used by the schools, were left with host teachers to be completed by the students in all classes approximately two weeks after the researcher had visited. Two weeks was an arbitrary time period that was agreed upon with the host teachers in order to minimise disruption to their teaching subsequent to the intervention. Teachers agreed to suspend further teaching of this topic until after the assessment items had been completed. The assessment items contained only content relevant to that which was taught in the intervention and control lessons. The same assessment items were presented to students in both classes. (See Appendix B for assessment items.)

3.2.3 Research design for the questionnaire and group interviews

The section of the questionnaire probing student attitudes and the subsequent group interviews were rooted in an anti-positivist rationalism. Qualitative research that gathers non-numerical data allows for the analysis of thoughts and feelings (Johnson and Christensen, 2014); it therefore provides a rich and illuminating data set that represents individual thoughts, feelings and attitudes. These data can help to both inform and explain the quantitative findings. Any research questions relating to student perceptions of the intervention pedagogies will tend towards the gathering of qualitative data. It has been claimed by Bryman (2012) that meaning is attributed by people to events and the environment that those events occur in, and that therefore a methodology is required that reflects these differences between individuals. Bryman (2012) also presents the idea that by seeing situations through the eyes of others there is the possibility of viewing things that were unanticipated by the researcher.

It was shown earlier that the research sub-questions ii, iii and iv are linked to student perceptions, and so it was appropriate to obtain information directly from the participants in the study about how they felt about the lessons they had experienced. The use of questionnaires allows a large amount of data to be obtained quickly. As Cohen and Manion (1994) point out, the value of a methodology that combines questionnaires and group interviews is that a large amount of questionnaire data can be sifted through and *interesting* answers identified and then probed in more detail with a smaller number of participants in the interview situation.

Typically, questionnaires include questions and statements that might focus upon behaviour, attitudes, opinions, beliefs and values, as well as knowledge (Johnson and Christensen, 2014). For the purposes of this study, a questionnaire was designed that primarily used Likert scale and free response items; this allowed data to be collected from all students involved in the intervention and control lessons, subject to their consent having been given. These data, in conjunction with the quantitative data from the quasi-experimental intervention, were used to identify a sub-group of students that were invited to participate in subsequent group interviews in order to explore their answers in more detail. The selection process for these group interviews will be described in more detail in Section 3.5.3. The questionnaires were also used to collect semi-quantitative data because if questionnaires are constructed with Likert scales then they can provide ordinal data for statistical analysis.

Data can be collected directly and in person in a number of ways, including: focus groups and either individual or group interviews. The latter were selected for use in this study as they occupy the middle ground between individual interviews and focus groups. Individual interviews were rejected due to the fact that they can be very time consuming and so, as a result, fewer individuals can be interviewed within the time available (Bryman, 2012). This type of interview also, by definition, does not allow for the development of interactions other than that between the researcher and participant, and therefore the richness of data collected may be limited. In the context of this study, in which it was important to explore emergent themes, this method was judged to be less desirable than group interviews.

In many respects, group interviews are a series of individual interviews carried out simultaneously. The researcher has a series of pre-planned questions and asks individuals to answer, often in sequence. However, as May (2011) points out, the degree to which participants interact with one another, in order to discuss and clarify opinions, is at the discretion of the interviewer and so, as such, the distinction between group interviews and focus groups is blurred. Although there is a risk that one or more interviewees may dominate the conversation, there is also the possibility that a number of different views may become apparent and certain instances of individual bias counterbalanced by alternative opinions (Arksey and Knight, 1999). It is also possible to present stimulus materials in order to promote discussion and to encourage participants to say more about a topic (Chrzanowska, 2002). Chrzanowska claims the material "triggers cues and associations, giving a richer response than unprompted questions" (2002, p.122).

The number of participants in a group interview varies but in the social sciences it is typically 4-9 (Bryman, 2012). The group needs to be of a size that both allows all the participants to contribute whilst also ensuring there is a diversity of ideas (Krueger, 1994; Morgan, 1988).

Focus groups, which encourage interaction between participants, were also rejected for this study. Focus groups allow participants to articulate the extent to which they either agree or disagree with responses made by other participants in the group. In such groups, the researcher relinquishes a degree of control over what is being discussed and may find that some of the focus group discussions are not relevant to the research (Bryman, 2012). Group interviews were selected in preference to focus groups due to the fact that the participants did not know the researcher well and so there was, therefore, a possibility that there would be very little group interaction in front of an 'outsider'.

Considering the points made above it was decided that group interviews would be used. It was also decided that there would be stimulus material provided to encourage a range of viewpoints to emerge.

3.3 Summary of the study

What follows is a broad overview of the lessons in the study, to enable the reader to appreciate the key differences between the lessons for the examination-style question and drama groups.

Irrespective of the group (examination-style question or drama) or phase of the study, each lesson commenced with a researcher led introduction to the new chemistry. This was followed by the main section of the lesson where students were able to consolidate and demonstrate their learning.

In the case of the examination-style question group, for all three phases of the study, during the main section of the lesson students completed a number of practice examination-style questions then used the mark scheme provided to self-mark these questions. Students were able to work together and discuss their answers with each other and the researcher.

In the main section of the lesson for the drama group in Phases 1 and 2, students worked in groups using a script and props provided by the researcher to practice the enactment of a physical representation of the reaction they had been allocated. Subsequently the groups acted out their simulation-role-play to the rest of the class and shared the associated symbolic equation.

The main section of the drama group lessons in Phase 3 of the study involved students working in groups to select props from a range provided by the researcher, writing their own scripts and practicing the enactment of a physical representation of the reaction they had been allocated. Subsequently the groups acted out their simulation-role-play to the rest of the class and shared the associated symbolic equation.

The research was divided into three phases, as opposed to the two stages in the original design described in Table 3.1. Phase 1 was the same as Stage 1; Phase 2 was a scaled down version of Phase 1 with minor alterations to the lessons and a new cohort of students. Phase 3 was a second intervention with students from Phase 2 (as in Stage 2 of the original plan).

The sample sizes for each phase of the study are as follows. Phase 1: n(drama) = 81, n(examination-style question) = 89. Phase 2: n(drama) = 32, n(examination-style question) = 34. Phase 3, a sub set of Phase 2 students: n(drama) = 7, n(examination-style question) = 17.

The factors that were pertinent in both causing and necessitating this adjustment in the sample sizes were as follows. The number of schools was reduced on moving from Phase 1 to Phase 2 and a new student cohort participated. When considering the decline in numbers on moving from Phase 2 to Phase 3 there were two factors. First of those was the decision made by some students to cease studying chemistry at the end of the first year; this led to a straightforward decrease in the number of participants. The second factor was the movement of some students from one group to another, within the same school/college, at the start of the second year of studies; this resulted in a situation wherein some of those students who had been in the drama group during Phase 2 were in the examination-style question group in Phase 3, and vice versa. To counter that second development, only data that pertained to students who had remained in the same group (control or intervention) for both visits were included in the data analysis.

In all three phases, the intervention lessons were followed up by assessment items that were completed by the students approximately two weeks after the lessons had taken place. In Phases 1 and 2, following the intervention lessons, all students were given the opportunity to complete questionnaires. Group interviews were conducted at the conclusion of all three phases.

In each school or college taking part in the study, there were two A Level Chemistry classes and both classes were studying the same chemistry theory. In the control class, the middle section of the lesson, aimed at consolidating learning, centred around examination-style questions; in the intervention class, by contrast, the middle section of the lesson comprised of drama activities completed in groups. The students in the drama groups in Phases 1 and 2 worked with scripts provided for them whilst students in the drama groups of Phase 3 used drama scripts that they had written themselves. Approximately two weeks after the intervention lessons, all students completed assessment items and, in Phases 1 and 2, were also invited to complete a questionnaire. In all three phases, answers to the assessment items, and also the questionnaire answers from Phases 1 and 2, resulted in a sub-set of students from each class being invited to take part in group interviews. The three phases of the study are summarised in Figure 3.1.

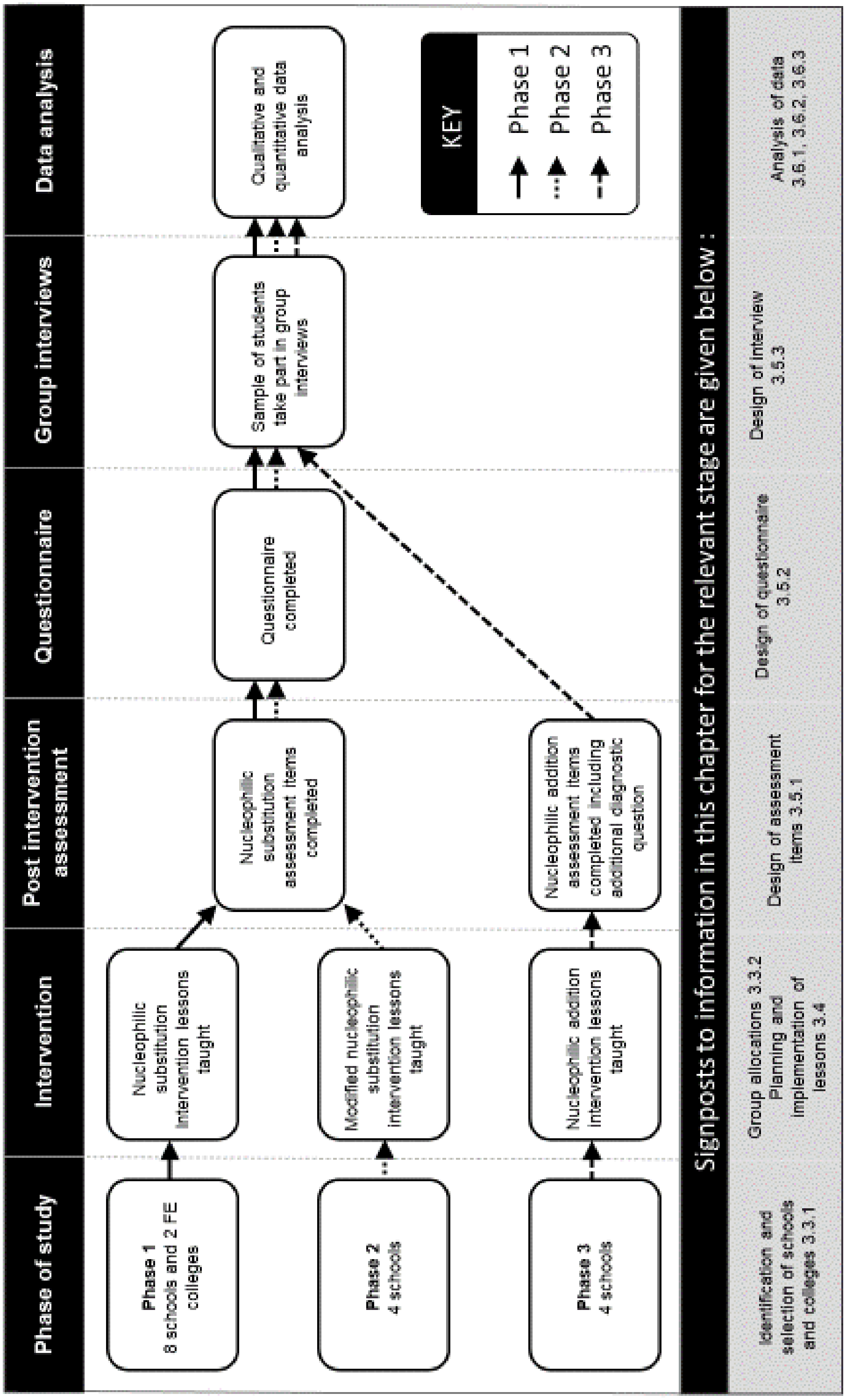


Figure 3.1 An outline of the three phases of the study

3.3.1 Selection of schools and colleges for the study

Staff in schools and colleges offering Chemistry A Level and located within a two-hour driving distance of the researcher were approached to take part in the study. In order to be eligible, the school or college also needed to have a minimum of two Chemistry A Level classes running concurrently with students in the first year (Y1) of their study.

This strategy yielded eight 11-18 schools, (two independent and six state schools) and two further education colleges. These centres were used in the first large scale gathering of Y1 data in the academic year 2014-2015 (Phase 1). Unfortunately, although initial indications from the centres was that the Y2 topic (nucleophilic addition) identified for the second set of intervention lessons would be taught in the academic year 2015-2016, seven centres went on to teach the topic in the summer term of Y1. The researcher was therefore unable to teach the second intervention lessons, and it was decided to instead repeat the intervention in 2015-2016, including minor alterations in response to the data collected in 2014-2015 (see Section 3.4.3 for details).

A further difficulty arose from the fact that A Level courses underwent a curriculum review for first teaching from September 2015. One of the specifications (OCR B) implemented a change of teaching order, so nucleophilic substitution was no longer the first organic mechanism met in that A Level course, and therefore schools and colleges following this course were removed from the study for Phases 2 and 3. Consequently, two state schools and one independent school were removed from the study. One independent school had also decided to teach the order of the topics differently and so was likewise no longer included in the study from 2015-16 onwards. Additionally, one further education college declined to take part in the study beyond Phase 1 due to time pressures, whilst the other further education college had staffing issues and did not reply to requests to be involved in the study in 2015-16. The remaining four schools for Phase 2 were all

11-18 state schools. These four schools continued into Phase 3 of the study.

3.3.2 Selecting which class experienced drama and which experienced examination-style questions lessons

The decision as to which of the two classes in a school experienced the drama lesson, and correspondingly which had the examination-style question lesson, was made randomly by the toss of a coin.

3.4 Details of the lesson interventions for the three phases

3.4.1 The chemistry taught in the intervention lessons

Organic reaction mechanisms were selected as the chemistry content for the study. This was considered to be suitable for the study for the following reasons:

i. Organic reaction mechanisms are not studied for the GCSE qualification, pre-A Level. They form no part of any of the GCSE specifications, either dual award or single sciences. As a result, it was extremely unlikely that any of the students participating in this study would have met the topic before, irrespective of prior chemistry education. This therefore minimised any potential impact of prior learning upon the results of the study.

ii. The topic of organic reaction mechanisms has been identified as being challenging for A Level students (AQA, 2013; OCR, 2011; OCR, 2014; Pearson Edexcel, 2009) and therefore may benefit from the use of alternative classroom pedagogies.

iii. Organic reaction mechanisms involve the movement of electrons to break existing chemical bonds and form new chemical bonds. It is possible to model such ideas using the movement of human bodies, aligning with the work of Bruun and Christiansen (2016) and Hostetter and Alibalia (2008).

iv. The A Level specifications for chemistry derive from the Department for Education guidelines (Department for Education, 2014b) and divide organic reaction mechanisms into sections to be covered in each of the two years (Y1 and Y2) of the A Level course. These sections are: nucleophilic substitution and electrophilic addition, studied in Y1; nucleophilic addition and electrophilic substitution, studied in Y2. Accordingly, the topic is appropriate for a longitudinal study over the two years of the course.

v. The reaction mechanism content has common features across all of the A Level courses. Consultation with teachers in the schools and colleges taking part in the study indicated that nucleophilic substitution was the first mechanism to be taught in Y1, making it a suitable starting point for the study in Phases 1 and 2, as there would be no prior teaching on reaction mechanisms from the class teacher. Similarly, the host teachers in schools identified that nucleophilic addition was the first mechanism to be studied in Y2 of the course, and would therefore be a suitable topic for Phase 3 of the study. For each of the phases of the study common statements across the specifications were identified; this allowed clear learning outcomes to be defined for all of the lessons in the study, and these were subsequently used to inform lesson planning. Feedback from Phase 1 (2014-2015) indicated there was a need to reduce the amount of work covered in the lesson, therefore for Phase 2 (2015-2016) the lessons were altered accordingly. All lesson plans can be seen in appendix A.

For Phase 3 (2016-2017), learning objectives and corresponding lesson plans for the teaching of nucleophilic addition were defined and written using specification statements common across all three examination boards.

What follows in Sections 3.4.2, 3.4.3 and 3.4.4 are details relating to the classroom interventions.

3.4.2 Phase 1: large-scale data collection in academic year 2014-2015

During the academic year 2014-2015, the first data sets were collected as in the outline given in Figure 3.1. Data were not collected for this cohort in Y2 as it was decided to instead slightly alter the Y1 intervention lessons. For the rationale behind that decision, see Section 3.4.3.

The lessons in Phase 1 were designed to address specification statements relating to nucleophilic substitution common to all the A Level courses current at the time (AQA, 20O7; Pearson Edexcel, 2013; OCR, 2008a, OCR, 2008b). The statements that were chosen stipulated that students should:

i. Understand that haloalkanes (halogenoalkanes) contain polar bonds.
ii. Understand that haloalkanes (halogenoalkanes) are susceptible to nucleophilic attack by OH^-, CN^-, NH_3 (AQA), hot aqueous alkali, H_2O (OCR), OH^-, H_2O, NH_3 (OCR B), alcoholic KOH, alcoholic ammonia, aqueous alkali (Pearson Edexcel).
iii. Understand the mechanism of nucleophilic substitution in primary haloalkanes.

In the following sections, the intervention class will be referred to as the drama class and the control class will be referred to as the examination-style question class. Where the term intervention is used in relation to the project as a whole, it refers to the lessons taught to both the control and intervention classes. Copies of the lesson plans and associated documentation for both groups and all phases of the study can be seen in Appendix A.

Phase 1 drama class lessons

The drama class outline presented in Table 3.2 is based upon a 60-minute lesson that was common to all the schools and colleges in the study. Photographs of the kit referred to in the consolidation phase of the lesson can be seen in Appendix A.1.10. The allocated times are approximate and are taken from the relevant lesson plan.

Table 3.2 Outline structure of the drama lesson in Phase 1

Phase	Time allocated in lesson plan (minutes)	Activity
Brief introduction	5	Researcher talk.
Recap of previous knowledge	10	Happy Families card-sort.
Introduction to new content	15	Researcher led simulation-role-play and explanation.
Student consolidation of content	25	Students work in small groups to practice acting out a simulation-role-play of one reaction using a script and kit provided by the researcher. Groups act out their simulation-role-play for the rest of the class and the 'audience' takes notes.
Explanation of next steps of the study	5	Researcher talk.

The outline of the structure of the examination-style question lesson, based upon a 60-minute timing, is summarised in Table 3.3. It can be seen that the format of the lesson was similar in structure and timings to that of the drama classes except that the introduction to new content did not involve the use of a simulation-role-play and instead comprised solely of researcher instruction with interactive questioning. Secondly, student consolidation involved working through a number of examination-style questions, followed by self-marking, instead of practicing and presenting the simulation-role-play and completing worksheets based on the drama observations.

Table 3.3 Outline structure of the examination-style question lesson in Phase 1

Phase	Time allocated in lesson plan (minutes)	Activity
Brief introduction	5	Researcher talk.
Recap of previous knowledge	10	Happy Families card-sort.
Introduction to new content	15	Researcher-led question and answer and explanation.
Student consolidation of learning	25	Students work on answering examination questions, either individually or with students on the same desk. They can ask the researcher or host teacher for help. Students self-mark answers using the mark scheme provided.
Explanation of next steps	5	Researcher talk.

3.4.3 Phase 2: smaller-scale data collection in academic year 2015-2016

Although the specifications for all examination boards had been reviewed, and updated in line with government requirements, there had been no change to the specification statements pertaining to organic reaction mechanisms, and therefore the learning outcomes for the lesson taught in Phase 2 remained the same as in Phase 1 of the study. Intervention lessons from 2014-2015 informed research design for the academic year 2015-2016. A sub-set of four schools from the ten that were originally participating were involved in Phase 2 and a revised pair of lessons were drawn up. The same examination-style question was added to both the drama and the examination-style question lessons and the details of these changes now follows.

It became clear from student responses and follow-up conversations with the host teachers that there was too much content for 60 minutes, and so the lessons were modified for Phase 2 of the study. Host teachers stated that, had they been teaching the lessons (with both drama and examination-style question groups), they would have split the content across two lessons. They suggested that they would have introduced the mechanism with the hydroxide ion (OH^-) and cyanide ion (CN^-) as nucleophiles in the first lesson and then developed the mechanism involving water (H_2O) and ammonia (NH_3) as nucleophiles in the second lesson. The reason for this change being that the involvement of water and ammonia adds an additional step to the reaction and thus makes it more complex. In the group interviews, students in the drama group reported that they felt unfairly disadvantaged since they had not seen any sample examination questions before completing the post-intervention assessment items. As a result of that concern, a section of the drama lesson in Phase 2 was allocated for the completion of one examination question, just as in the examination-style question group lesson.

Taking into account the comments above, the lesson for the drama group was also modified to remove water and ammonia as examples of nucleophiles. The Happy Families activity was also removed. Use of this activity in Phase 1 had revealed it was redundant since the only area that needed clarification was that X can be used as a general symbol for any halogen, e.g. CH_3X is a generic formula for any halomethane. This idea was incorporated into the introduction of new content section of the lesson. The extra ten minutes gained by not doing the Happy Families activity was utilised to complete and self-mark one examination-style question. This was an identical question to one completed by the students in the examination-style question classes. Both drama and examination-style question groups were allocated the same amount of lesson time to complete this written question. An outline structure of the revised drama lesson for Phase 2 is shown in Table 3.4.

Table 3.4 Outline structure of the drama lesson in Phase 2

Phase	Time allocated on lesson plan (minutes)	Activity
Brief introduction	5	Researcher talk.
Introduction to new content	15	Researcher-led simulation-role-play and explanation.
Student consolidation of content	25	Small group work where students practice and act out simulation-role-play of one reaction using script and kit provided by researcher. Groups act out their simulation-role-play for the rest of the class and 'audience' complete notes.
Linking simulation-role-play to written assessment	10	Students complete and self-mark one examination-style question.
Explanation of next steps	5	Researcher talk.

Taking into account the comments above, the lesson for the examination-style question group was also modified to remove water and ammonia as examples of nucleophiles. The Happy Families activity was also removed for the same reasons outlined earlier in this section. The extra ten minutes gained by not doing the Happy Families activity was in this case utilised to complete and self-mark one more past examination question. This was an identical question to that completed by the students in the drama classes. Both drama and examination-style question groups were allocated the same amount of lesson time to complete this written question. An outline structure of the revised examination-style question group lesson for Phase 2 is shown in Table 3.5.

Table 3.5 Outline structure of the examination-style question lesson in Phase 2

Phase	Time allocated in lesson plan (minutes)	Activity
Brief introduction	5	Researcher talk.
Introduction to new content	15	Researcher-led question and answer and explanation.
Student consolidation of content	25	Students work on answering examination questions, either individually or with students on the same desk. They can ask the researcher or host teacher for help. Students self-mark answers using the mark scheme provided.
	10	Students complete and self-mark the same examination-style question used in the Phase 2 drama lesson.
Explanation of next steps	5	Researcher talk.

3.4.4 Phase 3: data collection in academic year 2016-2017

In the academic year 2016-2017, the same centres and classes that had taken part in Phase 2 continued to participate in Phase 3. In Phase 3, the drama group students were writing their own scripts in the consolidation section of the lesson. They acted out these scripts and utilised a range of props that were provided by the researcher. Photographs of these props can be seen in Appendix A.2.5. Swick (1999) has postulated that student engagement increases if they write their own scripts, and Bateson (1994) has also argued that the use of scripts leads to enhanced learning. By contrast, the examination-style question group in Phase 3 were answering and self-marking examination and examination-style questions.

Lessons in Phase 3 (academic year 2016-2017) were designed to address the following statements relating to nucleophilic addition that are common to the three relevant specifications (AQA, 2017; OCR, 2019; Pearson Edexcel, 2018):

i. Outline the nucleophilic addition mechanism for reduction reactions with $NaBH_4$ (AQA and OCR A) $LiAlH_4$ in dry ether (Pearson Edexcel) (the nucleophile should be shown as H^-).
ii. Write overall equations for the formation of hydroxynitriles using HCN.
iii. Outline the nucleophilic addition mechanism for the reaction of aldehydes and ketones with KCN followed by dilute acid (AQA) or water (OCR), HCN in presence of KCN (Pearson Edexcel).
iv. Explain why nucleophilic addition reactions of KCN, followed by dilute acid, can produce a mixture of products.
v. Use curly arrows, relevant lone pairs, dipoles and evidence of optical activity to show the mechanisms above.

The lesson followed a similar format to earlier drama lessons, but this time the students consolidated learning by writing their own script for the simulation-role-play and acting this out. The lesson is summarised in Table 3.6.

Table 3.6 Outline structure of the drama lesson in Phase 3

Lesson phase	**Time allocated in lesson plan (minutes)**	**Activity**
Brief introduction	5	Researcher talk.
Recap of existing knowledge and introduction to new content	15	Researcher-led explanation.
Student consolidation of content	25	Students write their own simulation-role-play script and enact to the rest of the class using the kit provided. Students complete worksheets recording decisions about their simulation-role-play and script. They also write down the mechanisms for the simulation-role-play presentations they have seen and acted in.
Linking simulation-role-play to written assessment	10	Students answering and self-marking a sample examination question.
Explanation of next steps	5	Researcher talk.

Aside from its having been tailored to the teaching and learning of nucleophilic addition, the examination-style question lesson was similar in structure to that used in Phase 2. The structure for this lesson is summarised in Table 3.7.

Table 3.7 Outline structure of examination-style question lesson in Phase 3

Lesson phase	Time allocated in lesson plan (minutes)	Activity
Brief introduction	5	Researcher talk.
Recap of existing knowledge and introduction to new content	15	Researcher-led question and answer and explanation.
Student consolidation of content	25	Students complete and self-mark a number of examination-style questions.
	10	Students answer and self-mark examination-style question used in the Phase 3 drama lesson.
Explanation of next steps	5	Researcher talk.

3.5 After the intervention lessons

In each phase, approximately two weeks after the lessons that were taught by the researcher all the students involved were given assessment items to complete. Since the content had been slightly modified between Phases 1 and 2, the question relating to the use of ammonia as a nucleophile was removed from the Phase 2 assessment items. At the same time, the students were also invited to complete a questionnaire and a subset of those students were then invited to take part in a group interview. These three aspects are discussed in more detail in the following sections.

3.5.1 Assessment items

The context of this study is the post-16 education system in England. The numbers of students studying for A Levels is increasing (Joint Council for Qualifications, 2018) and the success or failure of students is judged upon their performance in written examination papers. This study, therefore, aimed to measure the performance of participating students through the use of past examination questions. These assessment items were selected from past papers from the three examination boards (AQA, OCR and Pearson Edexcel), with subsequent marking being carried out in accordance with the mark schemes provided by these boards. All examination questions since 2009 were reviewed for the chemistry relevant to the phase of the study and a selection from three of the four specifications identified (AQA, Pearson Edexcel and OCR A). Examination questions for OCR B (Salters) are synoptic in nature, drawing from across different parts of the chemistry specification in any given question and so, consequently, no questions from that specification were selected for use in this study. When the questions were selected, it was also ensured that different styles found in examination papers, such as short response and multiple choice, were represented.

The chosen questions were then compiled in a booklet for each of the students to complete under examination conditions in their schools approximately two weeks after the intervention lessons had taken place. These assessment items were completed by all of the participants in the study. The rationale behind their selection, are shown in Tables 3.8 and 3.9. Full versions of the assessment items, and their corresponding mark schemes, for the three phases of the study can be found in Appendix B.

Table 3.8 Summary of the examination board, date each assessment item was live, and the rationale behind selecting each item for use in Phases 1 and 2

Examination board	Date question was used in live assessment	Rationale for selection
AQA	Jan 2011	Description of reaction followed by explanation of key terms. Mechanism of nucleophilic substitution given reaction conditions.
OCR A	June 2010	Mechanism for nucleophilic substitution from a given equation.
AQA	Jan 2012	Mechanism for nucleophilic substitution. Reaction with a diol (needs appreciation that this is a dual reaction).
Pearson Edexcel	Jan 2010	Multiple choice.
Pearson Edexcel	June 2011	Application to completely new context.

The summary in Table 3.9 below shows the examination board, date when the assessment item was live and the rationale for selecting each assessment item used in Phase 3.

Table 3.9 Summary of the examination board, date each assessment item was live, and rationale for the selection of each item for use in Phase 3

Examination board	Date question was used in live assessment	Rationale for selection
OCR	Jan 2013	$NaBH_4$ as source of nucleophile, mechanism only.
AQA	June 2014	HCN as source of nucleophile, stereochemistry included.
Pearson Edexcel	June 2015	Multiple choice.

A diagnostic question with multiple answers, based upon student misconceptions, was also devised and added to the questions above in Phase 3. This question was peer-reviewed by three experts in the area of chemistry education prior to use. A copy of the diagnostic question can be seen in Appendix D.3.4.

3.5.2 Questionnaires

At the end of both Phase 1 and Phase 2, at the same time as the students were given the assessment items, they were also invited to complete a questionnaire. Written consent was obtained to use any of the data provided in the questionnaires.

The self-completion questionnaire was designed with both Likert scale and free response sections. Lozano et al. (2008) state that the optimum number of choices in Likert scale should be no fewer than four, and no larger than seven. Their basis for this claim is that three or fewer categories will not sufficiently differentiate responses and that more than seven may confuse respondents. There is some variance of opinion on this matter in the wider literature. Cox (1996), supports the idea that the most important factor determining the number of ratings in a comparative unidimensional scale should be appropriate to the task at hand. Peterson (2000) supports this, further arguing that a scale of five points or fewer is appropriate when a comparison of groups is required, as was the case in this study. The attitudes of students in this study towards chemistry will have been influenced by a range of factors, including their previous school experiences and chemistry teachers, and their personal reasons for opting to study chemistry in post-compulsory education. In the questionnaires, the Likert scales that relate to attitude are therefore designed to provide a comparison of students' attitudes towards their own experiences in the intervention lessons, therefore a maximum of five points was considered.

In terms of whether or not to include a mid-point in the scale, the literature suggests that there is evidence that respondents tend to gravitate towards the mid-point, often because there is a comfort in not having to commit or think too deeply about the answer (Newby, 2010). Accordingly, the Likert scales in the questionnaires used in this study were constructed with a 4-point scale: strongly agree, agree, disagree and strongly disagree. No midpoint option (such as 'don't know', 'don't care' or 'neutral') was included. Any respondent that added a midpoint response was removed from the data analysis for that item.

The questionnaire was also kept short in line with the prevailing view in the literature that this minimises the possibility of attention fatigue in respondents (Newby, 2010 and Gillham, 2000).

Adopting the advice given by Cohen and Manion (1994), the questionnaire was designed with different colours that demarcated the distinct areas of interest to the researcher, i.e. purple colouration indicated factual information and green colouration indicated questions concerning attitudes. This helps respondents to appreciate that each section has questions relating to different areas of interest. The Likert scales were devised in such a way that the respondents ticked a box to answer. Cohen and Manion (1994) identified this as being a familiar method for most respondents.

In the purple section of the questionnaire, factual information was gathered about background factors which *might* have impacted upon the participants' attitudes towards the intervention lessons and their learning. These factors were:

i. Gender.
ii. GCSE grades in science and type of science course followed at GCSE (dual award/single sciences).
iii. Current subjects being studied in Y1 in addition to chemistry.
iv. An estimate of frequency of pedagogy type experienced in Chemistry A Level classes in the preceding four teaching weeks.

In the green section of the questionnaire, the 4-point Likert scales were intended for use in statistical analysis and related to the students' attitudes:

Participants were asked to respond to the two statements:

i. I found the chemistry in this lesson easy to remember
ii. I found the chemistry in this lesson easy to understand

There were also the following 3 statements linked to a 4-point Likert scale along with the opportunity to provide a free response answer if desired:

i. Using drama/examination-style questions helped me to remember the chemistry theory in this lesson.

ii. Using drama/examination-style questions helped me to understand the chemistry theory in this lesson.

iii. Using drama/examination-style questions in this lesson helped me to complete the examination questions.

It has been claimed by Bryman (2012) that the addition of free response sections allows respondents to answer in their own words, with one result of that being the disclosure of opinions that might have been unforeseen otherwise. In addition, Chadwick, Bahr and Albrecht (1984) point out that people tend to respond better when they are speaking than when they are writing. It was for this reason that the free response answers were used solely to inform the decision as to which students would be invited to take part in subsequent group interviews. Section 3.5.3 will now detail the manner in which those answers were used as part of the selection process for group interviews.

3.5.3 Group interviews

In studies, participants might typically be selected for group interviews through a process of random selection that provides a subsection of the total population. In this study, however, this was not possible as, in line with the ethical approval granted for the study, students needed to give their consent in order to be approached to take part in any group interview. This requirement could have distorted the profile of the subset agreeing to be considered to take part in the discussions.

The use of purposeful selection has been suggested by Seidman (2013) to be a means by which to select participants for inclusion into a group in cases wherein qualitative data is required to be gathered but random sampling is neither suitable nor appropriate. This technique involves a considered selection of candidates. Patton (2002) suggests several approaches to that selection, including “typical case sampling”, “extreme or deviant case sampling”, “critical case sampling”, “sensitive case sampling”, “convenience sampling” and “maximum variation sampling” (pp.100-107). In Phases 1 and 2, the answers given for the free response question by all of the students who had consented to take part in the group interviews were collated, along with the name of their school, gender, predicted A Level grade, and the mark obtained in the post-intervention assessment items. On a school-by-school basis, consenting students, typically five or six, from the drama group were selected to be invited to participate in a group interview. Students were selected to be invited to participate using maximum variation sampling, as advocated by Patton (1989). When deciding who to invite the following groups of students were considered:

I. Students who had low scores in the assessment items but high predicted A Level grades.
II. Students who had high scores in the assessment items but low predicted A Level grades.
III. Students who had written that they found their intervention lesson useful/not useful for learning the relevant chemistry and/or answering examination questions.

In addition to these criteria, selection for group interviews was also guided to an extent by an aspiration to have a mix of male and female students in each group interview.

Invitations to take part in the group interviews were circulated via the host teachers and the interviews themselves took place in the schools. Most of the interviews were conducted during lunchtime or at the end of the school day; the host teachers were nearby but not present in the room. The absence of the host teacher from the interviews was intended to encourage a greater degree of frankness in the conversations than might otherwise have been missing. Some group interviews were carried out during chemistry lessons, with the students involved receiving permission from their teacher to be absent from the class. All of the times and dates for the interviews were negotiated with host teachers. There were some occasions, however, in which students who had been invited to participate in the group interviews were not in school on the day that it was conducted and so the host teacher had substituted another student in their place.

In Phase 3, a similar protocol was followed and, wherever possible, students who had been in the group interviews in Phase 2 were again invited to take part in those of Phase 3. In the case of two of the groups, because the class sizes were much smaller, the entire class took part by their own request.

In order to develop a greater sense of familiarity with the interviewees, the researcher initially spent time sharing snacks with them and discussing how the interview data would be used and stored. The pre-interview discussion also included an assurance that all contributions to the interview were valued and there were no wrong or right answers. This is in line with the approach advocated by Arksey and Knight (1999) who stress the importance of trust and rapport. Before starting any recording of the discussion, all participants were again asked whether they wished to withdraw from the interview situation.

For each interview, the initial question that was asked was “what do you remember, if anything, about the lesson taught by Miss Otter?”. One reason for this was that Arksey and Knight (1999) suggest that this kind of questioning is effective at putting interviewees at ease. In addition, in this case, it also served to focus the minds of the interviewees upon the lesson, which was useful as a form of preparation for the subsequent series of questions.

The group interview was divided into a number of sections. In order to abet the discussion during each of these stages, the researcher presented multiple printed statements that related to a specific aspect of the research questions, for example ‘using a script helps me remember the chemistry’ was shown alongside ‘using a drama script confuses me’. The stimulus materials were the same in both Phases 1 and 2 but were different in Phase 3. These statements emerged from the free response answers given in the questionnaires. (See Appendices D.1 and D.2 for the stimulus materials). During the interviews, the stimulus materials were presented in a neutral fashion and students were occasionally asked either for further information or as to whether there was anything else that they wanted to add. Towards the end of the interview, participants were invited to add anything else they thought might be relevant but had not been brought up in the interview. Interviews were 20-95 minutes in length.

Audio recordings were made of all the group interviews and, for one calendar month afterwards, participants were given the option to have any of their contributions removed from the record. After that time, the transcripts were anonymised so that no information could be traced back to any one individual.

3.6 Data analysis

The collected data fell into two broad categories: quantitative and qualitative. This section describes how each of the data sets were analysed.

3.6.1 Analysis of answers to assessment items

The marked responses to assessment items in the form of raw marks formed the basis for this data analysis. These data were recorded in an Excel 2013 spreadsheet, with one workbook per phase. The data were encoded using numerical designations.

Students' answers to the assessment items were marked using the corresponding mark schemes provided by the examination boards. However, it can be seen in Appendices B.1.1 and B.2.1 that in some cases a number of criteria needed to have been fulfilled before a mark could be awarded. In order to analyse whether or not there were any differences in performance in terms of meeting these individual criteria a more detailed mark scheme was produced. This is referred to, here, as the fine-grain mark scheme. To exemplify the links between the examination board mark scheme and the associated fine-grain mark scheme, one of the assessment item marks (question 2a, mark 6, Phase 3) is given in Table 3.10 below. In this case, it can be seen that three different criteria need to have been successfully met in order for the mark to be awarded according to the examination board mark scheme. The fine-grain mark scheme, however, awards a mark for each of the three individual criteria. Emboldened coding options are those designated as mark-worthy answers by the examination board mark scheme. The second and fifth column indicate the numerical coding for the relevant Excel workbook

Table 3.10 Sample of examination board and fine-grain mark schemes, mark 6 in the assessment items for Phases 1 and 2

1	2	3	4	5
Examination board mark scheme number and chemistry under consideration	**Coding options**	**Extra comments**	**Fine grain mark number**	**Fine grain marks Coding option 0=no mark awarded 1= mark awarded**
Mark 6 Arrow 1 source	0 no answer **1 arrow *from* lone pair or minus sign in CN^-** 2 attack from nucleophile from lone pair or –ve charge with lone pair or negative charge (where no attack is from missing) 3 attack from nucleophile, but which part unclear 4 other	Identification of source only	13	If 1 or 2 from column 2 award mark 13
Arrow 1 sink	0 no answer **1.Arrow to C in carbonyl group** 2 Arrow to another sink	Identification of sink only	14	1 from column 2 award Mark 14
Arrow 1 position	0 no answer **1 Arrow close enough to correct source and sink** 2 Arrow wide of correct source ***or*** sink 3 Arrow wide of correct source ***and*** sink 4 other	Location of arrow	15	If 1, 2, or 3 in column 2 award mark 15
Mark 6 awarded?	*0 no mark* *1 mark awarded*	*All of the above points must have been correctly addressed*		

Conditional formulae were applied in the Excel spreadsheet to calculate cumulative totals for student responses. Quantitative data analysis was carried out using the appropriate statistical tests using SPSS v23.

It was necessary to determine whether the data for each phase was parametric or non-parametric (see Chapter 4 for more detail). Data gathered in Phases 1 and 2 were deemed to be parametric whilst Phase 3 data were non-parametric.

It was also necessary to test whether or not there was a statistically significant difference between the predicted A Level grades of the two groups (drama and examination-style question) using an independent two-tailed t test in Phases 1 and 2 of the study. This determined whether or not there was a need to analyse any of the data using predicted A Level Chemistry grades as a covariant, “a variable that is related to the dependent variable, and can therefore confound the effects of the other variable” (Cramer and Howitt, 2004, p.64). This was found to be the case for Phase 1 data, meaning that the students’ predicted A Level grade had to be treated as a covariant in order to be disassociated from the effect of classroom pedagogy upon marks obtained. There was no statistically significant difference between the predicted A Level grades of the two groups in Phase 2. This meant the statistical analyses varied between phases of the study, as is summarised in Tables 3.11 and 3.12 below. The total marks awarded via both the examination board mark scheme and fine-grain mark scheme were analysed for differences between them in terms of the drama and examination-style question groups. They were also analysed for differences between marks obtained by the two groups with respect to gender and predicted A Level grade and relationships between marks obtained and the number of science, technology, engineering and mathematics (STEM) subjects being studied in addition to chemistry, as well as reported prior pedagogical experiences in A Level Chemistry classes. Deciding whether a subject is to be included under the STEM umbrella can be problematic, with a variety of definitions being used between different bodies and countries (Science and Technology, Lords Select Committee, 2012). The A level subjects classed as STEM by the Joint Council for Qualifications (JCQ) are biology, chemistry, physics, design and technology, maths, further maths, computing and "other sciences" (JCQ, 2013). These subjects were designated as STEM for this study; geology, psychology and geography were included as subjects falling under the definition of ‘other sciences’.

Table 3.11 Statistical tests adopted for the analysis of marks awarded using the examination board mark scheme in Phases 1 and 2

Data set	Required outcome	Phase 1 data analysis (parametric with predicted A Level grade as a covariant)	Phase 2 data analysis (parametric)
Total marks obtained in exam-board mark scheme	Difference between marks of the two groups using the examination board mark scheme.	1 way ANCOVA. Controlling for differences in predicted A Level grade	Independent two-tailed t test.
	Difference between group marks with respect to gender	2 way ANCOVA. Independent variables: classroom pedagogies (drama and examination-style questions) and gender (male and female). Controlling for predicted A Level grade	Two-way ANOVA. Independent variables: classroom pedagogies (drama and examination-style questions) and gender (male and female).
	Differences between group marks with respect to predicted A Level grade	Two-way ANOVA Independent variables: classroom pedagogies (drama and examination-style questions) and predicted A Level grade (high and low).	Two-way ANOVA. Independent variables: classroom pedagogies (drama and examination-style questions) and predicted A Level grade (high and low).
	Relationship between number of STEM subjects being studied and test mark.	Pearson's product moment correlation. Controlling for predicted A Level grade using partial correlations	Pearson's product moment correlation
	Relationship between previous classroom pedagogy (traditional and interactive) and test mark.	Pearson's product moment correlation. Controlling for predicted A Level grade using partial correlations.	Pearson's product moment correlation.

Table 3.12 Statistical tests adopted for analysis of marks awarded using the fine-grain mark scheme in Phases 1 and 2

Data set	**Required outcome**	**Phase 1 data analysis** **(parametric with predicted A Level grade as a covariant)**	**Phase 2 data analysis** **(parametric)**
Total mark obtained using the fine-grain mark scheme	Difference between marks of the two groups using the fine-grain mark scheme.	1 way ANCOVA Controlling for differences in predicted A Level grade.	Independent two-tailed t test.
Individual specific fine-grain mark scheme questions	Difference between marks for individual questions of the two groups using the fine-grain mark scheme.	Chi-squared.	Chi-squared.
Total mark from fine-grain mark scheme	Difference between marks obtained with respect to gender.	Two-way ANCOVA. Independent variables: classroom pedagogies (drama and examination-style question) and gender (male and female). Controlling for predicted A Level grade.	Two-way ANOVA. Independent variables: classroom pedagogies (drama and examination-style question) and gender (male and female).
	Difference between marks obtained with respect to predicted A Level grade.	Two-way ANOVA. Independent variables: classroom pedagogies (drama and examination-style questions) and predicted A Level grade (high v and low).	Two-way ANOVA. Independent variables: classroom pedagogies (drama and examination-style questions) and predicted A Level grade (high v and low).

Data set	Required outcome	Phase 1 data analysis (parametric with predicted A Level grade as a covariant)	Phase 2 data analysis (parametric)
Total mark from fine-grain mark scheme	Relationship between number of STEM subjects being studied and test mark obtained.	Pearson's product moment correlation. Controlling for predicted A Level grade using partial correlations.	Pearson's product moment correlation.
	Relationship between prior classroom pedagogy (traditional and interactive) and test marks obtained.	Pearson's product moment correlation. Controlling for predicted A Level grade using partial correlations.	Pearson's product moment correlation.

The non-parametric nature of the data from Phase 3 limited the range of analyses that could be carried out. Differences between the two groups were analysed using the total marks given by the examination board mark scheme and the total marks obtained according to the fine-grain mark scheme. The variation in answers to the diagnostic question were also analysed. The statistical analyses used are summarised in Table 3.13.

Table 3.13 Statistical tests adopted for Phase 3 data

Data set	Required outcome	Statistical test
Total marks obtained in examination board mark scheme.	Difference between marks of the two groups using the examination board mark scheme.	Mann Whitney U
Total marks obtained using the fine grain mark scheme.	Difference between marks of the two groups using the fine-grain mark scheme.	Mann Whitney U
Diagnostic question answers.	Difference in the range of answers given by the two groups to the diagnostic question.	Standard score (z-score)

3.6.2 Analysis of questionnaires

In order to perform the analyses detailed in Tables 3.11 and 3.12, the following groups of data were coded and stored under unique identifiers for each student: gender, school attended, predicted A Level Chemistry grade, and subjects being studied other than chemistry. There were also data from the 4-point Likert scales relating to the types of lessons that students had experienced in their A Level Chemistry classes during the previous four weeks. Additionally, data were also provided by the 4-point Likert scales relating to whether the students had found the lesson they had experienced to have helped them to remember and understand the chemistry or to prepare for answering examination questions.

The questionnaires yielded three types of data:

i. Factual data.
ii. Likert scale ordinal data.
i. Free response written answers.

Each of these data sets was processed differently.

Factual data gathered from Section 1 of the questionnaire was both nominal (e.g. gender) and ordinal (e.g. predicted A Level grade).

These data were coded for each individual student and entered into the Excel spreadsheet alongside all of the assessment item responses. A small sample of the coding schedule is shown in Table 3.14 below.

Table 3.14 Section of coding schedule relating to grades previously attained in GCSE science

Subject of data	Allocated coding
Grades previously attained in Science.	0 = no data
	Additional Science grade 1 = A* 2 = A 3 = B 4 = C
	GCSE Chemistry grade 5 = A* 6 = A 7 = B 8 = C 9 = D
	10 = other

Responses from the 4-point Likert scales were all coded using a 0-5 scale as follows:

0 = no response
1 = strongly agree
2 = agree
3 = disagree
4 = strongly disagree
5 = other

These data were entered, for each individual student, into the Excel spreadsheet. Mann Whitney U tests were then conducted in order to statistically analyse differences between the mean scores of the two groups' (drama and examination-style question) answers to the following statements:

i. I found the chemistry in this lesson easy to remember.
ii. Using drama/examination-style questions helped me to understand the chemistry theory in this lesson.
iii. Using drama/examination-style questions in this lesson helped me to complete the examination questions.

The final data obtained from the questionnaire were the free response answers. These were all noted and given a reference code relating to the student, the school, and the intervention group. These qualitative data were used to support decisions made on who was invited to participate in the group interviews.

3.6.3 Analysis of data from group interviews using grounded theory

One form of qualitative data gathered in this study were the audio recordings of a number of group interviews. These recordings were transcribed using software that allowed the researcher to simultaneously read and listen to the discussions that comprised the interviews. The questionnaires, completed by all the students in the study, had provided a number of ideas that informed the stimulus statements for the group interviews. It cannot, however, be assumed that these gave a complete representation of the students' thoughts and opinions. As Chadwick, Bahr and Albrecht (1984) have argued, written responses do not always yield the full picture. Group interviews allowed students to raise a wide range of responses to the stimulus statements provided and to add any additional thoughts.

One method by which sense can be made of the large amounts of data collected from group interviews is to use the Grounded Theory approach, first developed in 1965 by Glaser and Strauss as a methodology by which grounded theory can be derived inductively from data through the use of coding and constant comparative method (Chun, Birks and Francis, 2019). The methodology is both flexible and complex and has been widely used in the fields of social science and medical research.

With grounded theory, the first step in analysis involves qualitative coding. Coding in this context refers to the naming of short sections of data in a manner that summarises and accounts for that data (Charmaz, 2006). These initial codings form the basis of future development of theories and so need to be as wide ranging as possible, with the researcher remaining open-minded to all options that emerge. This coding should be active and fluid, with new codes constantly being created by the researcher (Charmaz, 2006). Clarke (2005) has pointed out that the reality of the process of codification is a construct between the realities of both the participants (in this case, students) and the researcher. The codes in this study were devised through the process of the researcher's interaction with the words of the interviewees. This active construction from the data, rather than searching the data for examples to endorse pre-ordained theories, has led to the use of the term 'constructivist grounded theory' in order to emphasise the active crafting of the processes involved (Mills, Bonner and Francis, 2006). As a result of this perceived subjectivism, grounded theory has its critics. It has been criticised as being "impressionistic, anecdotal, unsystematic and biased" (Charmaz, 2014, p.6). As early proponents of grounded theory, Glaser and Strauss (1967) challenged such criticisms, claiming that systematic qualitative analysis has its own logic. Grounded theory offers methodical and open-ended guidelines about the collection and analysis of qualitative data (Charmaz, 2014). This researcher tried to bring an open mind to the data to maximise the extent to which that which had been articulated by the students in the group interviews was included in the analysis. This way of working was designed to reveal richness of thoughts, feelings and ideas that might not otherwise have been found had the data been analysed in a more pre-defined way (Glaser,1998; Strauss and Corbin,1998). That notion is also considered to an extent by McCallin (2003) when they argue that, at the very least, any postgraduate researcher will have necessarily engaged with relevant literature in order to have written a research proposal and therefore be influenced during data analysis by what they have already read. In mitigation, Dey (1999) has stated "There is a difference between an open mind and an empty head" (p.251), indicating the need to both be aware of the subject under study but also to attempt to be as unbiased as possible in the data analysis. It would be naïve to assume that any researcher performing data analysis using grounded theory will be completely unaware of the area of research. Glaser (1998) advocates that, in order to reduce the influences of pre-reading on the results of the analysis, the literature review should take place after the data analysis is complete; this is what was done in this study.

The richness of coding in the initial stages of the process, coupled with the constant comparison of the codes for similarities and differences, allows codes to be brought together into themes, known as categories. Constant iterations of the process, whereby the codes and categories are compared with each other, will eventually lead to the categories reaching saturation. This is the point at which no more categories can be constructed from the data. It can be seen in Figure 3.2 that Tweed and Charmaz (2012) include the use of theoretical sampling during the initial period of data analysis. Here they are advocating that if any areas are in need of elaboration or refinement then further data must be collected in order to provide elucidation. This theoretical sampling involves going back to selected interviewees who can add to the relevant codes and or categories needing further data (Charmaz, 2006). There were no opportunities in this study to revisit the same students for extra inputs, but there were a number of group interviews at each phase. Due to this set of circumstances it is more accurate to say that the analysis of the group interview transcripts was *informed* by grounded theory methodology but that it did not follow it exactly.

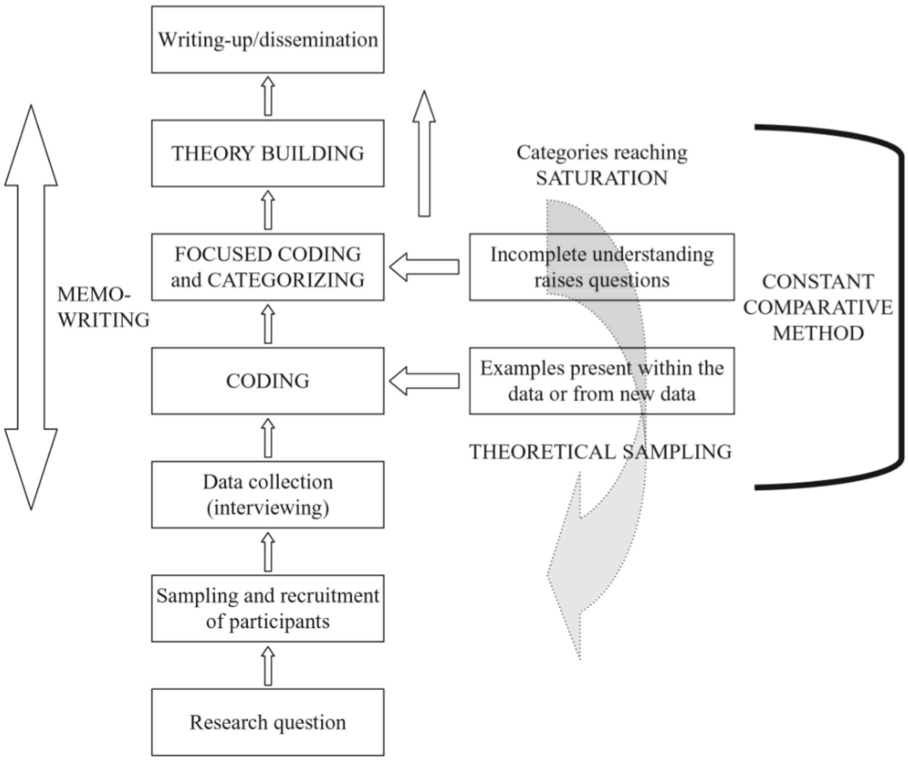


Figure 3.2 A visual representation of grounded theory (Tweed and Charmaz, 2012, p.133)

The literature review (Chapter 2) identified a current paucity of research that considers drama, including simulation-role-play, as a teaching and learning pedagogy and examines the impact that it has upon the learning of scientific concepts, particularly in Key Stage 5. As such, it was decided that it would be more fitting to use emergent themes that were appropriate to the study rather than pre-existing themes from other studies, despite the inability to carry out theoretical sampling. Following the initial coding and categorisation, the data were revisited so that additional codes and categories could continually be added in response to any questions that were raised as the data were analysed: a methodological practice recommended by Seidman (2013). This allowed for a more rich and open-ended interpretation.

It has been pointed out that there are often pragmatic limitations in how much data can be obtained via ongoing theoretical sampling

(Tweed and Charmaz, 2012). In Phase 1 of data collection, group interviews were conducted with each of the eight drama groups that had contributed quantitative data; this ensured that all of the participating schools and colleges were represented. In Phase 2, representatives from three of the four drama groups took part in group interviews. In Phase 3, only two of the four participating schools were used for group interviews; this lower number was linked to availability of students. In particular, the proximity of the external examinations at the time of the year in which those interviews were conducted in Phase 3 was an important factor: host teachers were reluctant to give more time to the study as the examinations became imminent. However, in two of the schools, following the Phase 3 intervention lessons, the entire class from the drama group requested to take part in the group interviews.

Birks and Mills (2011) stress that there is a need to continually hold the research questions in mind when analysing the qualitative data in order for depth of analysis to take place. Clarke (2005) also promotes the strategy as a means to prevent the researcher from becoming overwhelmed by the volume of data. This point was itself held in consideration when the data were analysed in this study. Initial coding of the transcripts took place using a technique that Seidman refers to as “close reading and judgement” (2013, p.120). The transcripts were simultaneously read and listened to and, during that process, chunks of text were highlighted as being of interest and worth revisiting. This initial stage ensured the removal of incidental parts of the interview where, for example, students had gone off topic or the interviewer was talking about data storage. It also highlighted that in some of the earlier Phase 1 interviews, the researcher, due to inexperience, had asked leading questions and had also tried during the interview to interpret what the group participants were trying to say. Those transcripts were consequently discarded from the data set in order to maintain its validity; this reduced the number of Phase 1 transcripts to three.

Open coding, described as the process by which the narrative whole is fractured into many diverse pieces (Priest, Roberts and Woods, 2002) was the next stage. The units of analysis for codification were individual responses from students, using short segments of transcribed words, in line with Glaser (1978) who advocated this strategy. It was later argued by Glaser (1992) that the use of this coding paradigm also reduces the likelihood of the data being forced into a pre-existing theoretical framework. A code, according to Birks and Mills (2011) is a form of "shorthand applied to reoccurring actions, characteristics, experiences, phrases [or] explanations" (2011, p.93). The codes in this study arose from interrogation of the data, in this case transcripts of the group interviews. Glaser and Strauss (1967) describe how this process of initial coding fractures the data, breaking it open into a number of different sections; this fracturing can allow episode-by-episode comparisons between applied codes.

There is some debate about how open any codification can be, since any researcher approaching coding will have a range of personal and/or professional experiences relating to their research. Birks and Mills (2011) discuss the idea that it is necessary for a researcher to acknowledge their baseline position with respect to their research. This researcher acknowledges having used a range of teaching and learning pedagogies, including drama, in the classroom in the course of their previous professional incarnation, and, in order to apply for a position as a researcher there was a requirement to submit a proposal, drawing on some relevant reading. Glaser (1992) cautions that the baseline position of any researcher raises the potential for the researcher to consciously, or unconsciously, apply existing personal ideas to the data. Theoretical sensitivity is advocated: that which Birks and Mills describe as "the ability to recognise and extract from the data elements that have relevance for your emerging theory" (2011, p.59). An awareness of any personal pre-conceptions is important in order to avoid forcing the codification of the data to try to maximise theoretical sensitivity.

The process of intermediate coding was then undertaken, and this coding followed naturally from the initial coding. During this stage of analysis, the many seemingly disparate codes were assembled in categories that were meaningful to the researcher. This process is referred to varyingly as selective coding (Glaser, 1978), focused coding (Charmaz, 2014) and axial coding (Strauss and Corbin, 1998) and involves making connections between different codes using a series of patterns and relationships. There was a particular need for the researcher to be aware of personal bias at this stage. This is a second level of conceptual development, aimed at drawing out themes from an initially disparate data set. The data needed to be continually read and reread, listened to and re-listened to. The grouping of codes in such a manner produced categories, containing a range of subcategories. Each category, and by definition its associated sub-categories, were linked by a common property, "a characteristic of a category, the delineation of which defines and gives it meaning" (Strauss and Corbin, 1998, p.101). The process of redefining categories by their properties led to emergent themes dominating in the analysis at this stage.

The third type of coding, theoretical coding, aims to bring together the different categories via relationships uniting them as a theory. For examples of coding and categories from this study see Appendix D.

3.7 Reliability

Reliability and validity are both terms that are frequently used within the field of education research. Broadly speaking, reliability relates to reproducibility of a result, i.e. whether or not the same results would be obtained if the study were repeated at different times in different places by different researchers. Validity is concerned with whether or not the research measures that which it sets out to measure (Golafshani, 2003). This section considers reliability in the context of this study and is then followed by a section that reviews validity. Reliability can be considered in terms of stability of measurement over a variety of conditions in which basically the same results should be obtained (Drost, 2011). In order to assist with this detailed accounts of this study are available, including all of the classroom resources, questionnaires and stimulus materials used in the group interviews allowing the study to be reproduced accurately.

Drost (2011) speaks of reliability in terms of consistency of measurement. With reference to the quasi-experimental section of the study, there is a need to be aware that reliability can be influenced by random errors. On the one hand, in the case of this study, a small percentage of students in the study might have been ill or experiencing other personal problems and so not have answered the assessment items as well as they might otherwise have done. On the other hand, it is also possible that some students' marks were determined by chance if they had simply guessed the answer and had not actually understood the chemistry. These scenarios introduce an element of randomness or unreliability to the results. Although these random variations cannot be eliminated their potential impact upon the results can be minimised by ensuring a suitably large sample size. The other type of error is systematic error, whereby the error alters results in a consistent direction: a marker might have consistently awarded a mark for the same incorrect answer (as defined by the mark scheme) and so have systematically inflated student scores. Although it is impossible to eliminate such errors measures were taken in this study to minimise the possibility of their occurrence.

3.7.1 Reliability and quasi-experimental interventions

The quasi-experimental sections of the study had four key design features that were intended to maximise reliability. Firstly, feedback from students in the pilot study was used to refine both the timings and resources for the intervention lessons. This ensured that all the required content was covered in a consistent manner across both lesson types. The drama and the examination-style question lessons were both constructed so that the chemistry content was introduced using the same examples (same content but different pedagogy).

Additionally, the time allocated to the different sections of the lessons was also the same, as was detailed in Sections 3.4.2, 3.4.3 and 3.4.4, which was also intended to reduce the possibility of variation in learning being dependent upon the use of different exemplars.

Secondly, a number of measures were taken specifically to minimise variation between the two groups other than the difference in pedagogical input. One such measure was that the researcher taught all of the lessons and so ensured a degree of consistency in terms of the teaching. Another measure was that the interval between the lesson and the completion of follow-up assessment items was kept as close as possible to two weeks for each school or college. The uniformity of this interval served to ensure that all answers had been given under similar circumstances; this reduced the possibility for reliability to have been compromised by intervals of different lengths having resulted in different lapses in memory.

Thirdly, in an attempt to reduce systematic error as a result of researcher bias, all responses to the post-intervention assessment items were blind marked: the researcher was unaware as to whether the scripts were those from a drama or an examination-style question class. Subsequently, a sample of student responses to the assessment items from Phase 1 (n = 19) and Phase 3 (n = 9) were also marked by experienced science teachers and the two sets of marks statistically analysed for variation. In neither phase of the study was any statistically significant difference found to exist between the marks awarded by the researcher and by other independent markers.

Fourthly, the two classes within each school were assigned either the drama or examination-style question lesson by random assignment (a coin toss) in order to remove the potential for any bias on the part of the host teacher or researcher.

3.7.2 Reliability and questionnaires

Feedback from students involved in the pilot study was used during the designing of the questionnaire in order to minimise the potential for questions to be viewed as unclear or ambiguous; this worked to reduce the possibility of errors occurring through misinterpretation of the questions. The same questionnaire was used in Phases 1 and 2 for both the intervention and control groups. The questionnaires were explicit in their connection to the research questions and, in order to reduce participant fatigue, the questionnaires were very short.

3.7.3 Reliability and group interviews

The same set of stimulus materials were used in Phases 1 and 2 to promote discussion in the group interviews; in Phase 3 a new and phase-specific set of stimulus materials were used instead to promote discussion. All of these materials were aimed at increasing reliability, by focusing the areas of discussion.

3.8 Validity

Validity is a gauge of the degree to which a study actually measures what the researcher claims it measures (Wellington and Szczerbinski, 2007) and its assessment therefore requires the identification of the variable that is being measured. In this study, the measured variables were: test marks; student perceptions as to how well aspects of a lesson contributed towards recall and understanding of the relevant chemistry; and, student perceptions as to how effective the use of drama (simulation-role-play) in lessons was in helping them answer A Level examination questions.

Validity takes two forms: internal and external. Internal validity relates to whether the research measures precisely what it intended to measure, whereas external validity is a measure of how generalisable the results of a study are (Adams and Schvaneveldt, 1991). The following discussion examines the different sections of the study and critically evaluates how the methodology impacts upon both its internal and its external validity.

3.8.1 Validity and sampling

Initial sampling was opportunistic but the schools and colleges involved in Phase 1 of the study included a range of different types of institutions: schools, both independent and state, as well as further education colleges. Across the cohort, students were studying A Level Chemistry courses provided by all three of the major examination boards. These two factors both served to enhance external validity as the results obtained can claim to better represent those that might be obtained in a wider sample of actual A Level Chemistry students. Unfortunately, this was not the case in Phases 2 and 3 of the study: in those phases, the sample of students was drawn solely from state schools.

3.8.2 Validity and quasi-experimental interventions

When designing the classroom intervention, a number of measures were incorporated into the design in order to enhance both internal and external validity. The intervention lessons were planned so as to be the same for both the drama and the examination-style question groups, with the crucial exception of a specified period of the lesson during which time the classroom pedagogy was different for each group. This improved the internal validity, as any differences between results of the two groups can then reasonably be attributed to the differing classroom pedagogies. The Internal and external validities were also increased by the fact that the intervention lessons were taught in the regular teaching spaces at the same time as host teachers would have normally taught this topic. The learning objectives for the two groups were also the same and common to all the different A Level specifications. Examination-style questions were all checked prior to use by practicing teachers who agreed that they were of the type that they would have used if they were teaching this topic. Authentic A Level examination questions were used as post-intervention assessment items and were drawn from across all of the relevant specifications. In addition, the diagnostic question used in Phase 3 was expert reviewed to ensure it pertained to the A Level specification and addressed student misconceptions. As a result of these measures having been implemented, this study can claim to have measured that which it intended to, and to have provided results that have a measure of generalisability.

A more contentious issue in terms of validity is the fact that all of the lessons in the study were taught by the researcher. On the one hand, this approach reduced variation in teaching style and bias from individual teachers, and in one sense increased internal validity. On the other hand, it could also be argued that external validity was reduced due to all of the lessons having been taught by one person who had a particular interest in the results. Whilst the lesson content was fixed and independent of the researcher, aspects such as body language and tone of voice are largely beyond the conscious control of the researcher.

3.8.3 Validity and questionnaires

The purpose of the questionnaire in this study was twofold. In the first instance, it was used to collect ordinal data relating to student attitudes towards both the recollection and understanding of the chemistry content and also the effectiveness of lessons they had experienced in helping them to answer A Level examination questions. These questions were clearly and directly linked to the research questions and were designed in such a manner as to reduce any ambiguity as to what was being asked. The limited 4-point scale on these questions could, to an extent, be argued to have reduced validity, as there is little nuance in the answers. As these questions were, however, primarily intended to get participants to focus upon the attitude being interrogated, a 4-point Likert scale, as advocated by Peterson (2000) was judged to be fit for purpose.

The second purpose of the questionnaire was to provide an insight into the thinking behind the responses given to the Likert scale statements; this was done by means of free response answers. In order to maximise the authenticity of the responses, no examples of possible answers were provided. These responses were then used to inform the stimulus materials used in the subsequent group interviews. Theoretically, this contributed to the enhancement of both external and internal validity due to the fact that all of the themes for discussion had been generated by participants in the study. As expected, though, not all of students contributed to the free response sections. Whether this lack of response was due to apathy, to writing overload (as they answered the questionnaires immediately following completion of the assessment items), or to the fact that there was nothing they wanted to say remains unknown. This meant that a small percentage of participants informed content of the stimulus materials used in the group interviews.

3.8.4 Validity and group interviews

Feedback from the pilot studies indicated that students felt that they would feel more confident (and therefore more likely to contribute and thus increase the validity of inputs) in a group interview situation rather than in individual interviews. Before thinking about validity in relation to the group interviews and the subsequent data analysis it is also important to briefly consider the impact of selection for the interviews, also in connection to the issue of validity. Measures were taken to select students using a maximum variation strategy (see Section 3.5.3); sometimes, however, individuals who had left comments in the free response section of the questionnaire were not invited to take part in group discussions due to the fact that they had not given consent to do so. Therefore, whilst selection via maximum variation sampling helped to increase internal validity, the fact that not all participants were prepared to contribute to the group interviews also narrowed the range of students for inclusion and so reduced both internal and external validity.

Validity of interview results can be problematic. For example, McNeill and Chapman (2005) raise what they call “interview effects” (p.59), and these effects include the status of the interviewer. Age, gender and social class are also examples of factors that may influence the responses given by interviewees. Another issue identified by McNeill and Chapman (2005) is that of “yea-saying” (p.63), a term that refers to interviewees giving answers that they think the interviewer wants to hear rather than what they actually think. Kitwood (1977) uses that concept of ‘yea-saying’ as part of a challenge to the idea of reliability and validity in interviews: he argues that the more that an interviewer becomes, in an attempt to increase reliability, “rational, controlled and detached, the less likely the interview will be perceived as a friendly transaction and the more calculated the response also is likely to be” (p.171). The argument that Kitwood (1977) makes is that a drive to increase the reliability of the interview leads to a decrease in the same human element that is required for greater validity.

The research design incorporated a number of strategies in order to try to increase both internal and external validity. Before each group interview, in an attempt to help students feel at ease, the researcher spent time sharing food with the participants. During that period, the researcher made it clear that the purpose of the study was to find answers to the research questions and that therefore there were no ‘right’ answers and all responses would be valued. In an attempt to increase internal validity, the researcher also maintained the same hairstyle and wore the same clothing for all interviews across a given phase. This was done so as to reduce potential variation in responses due to groups having different perceptions of the status of the researcher. The stimulus materials presented at each group interview within the same phase of the study were the same and generated in response to answers given in the free response section of the questionnaires; this further contributed to internal validity, as the topics for discussion were generated from student responses rather than by the researcher. Towards the end of each group interview, participants were encouraged to add anything else that they thought was relevant but that had not been covered prior to that point. The reasoning behind that final invitation to contribute was to ensure that as many of the participants ideas as possible were discussed, with this once again contributing to both internal and external validity. During Phase 3 group interviews, in order to try to minimise the domination of the group by any one individual member, students were presented with statements, each with a Likert scale. Before starting the group interviews, each interviewee marked, on the Likert scale, the degree to which they agreed with a statement. This meant all participants had made some decisions that were then presented to the group before the discussion itself began.

Analysis of the transcripts was carried out in a manner informed by grounded theory (see Section 3.6.2) which further contributed to both external and internal validity. As methodological steps were taken to ensure that the analysis was approached with an open mind, the emergent codes and categories can be seen as being more authentic than they would have been had the analysis been carried out with the intention of confirming pre-conceived answers. One concern in that regard, however, was that there was no opportunity to re-interview individuals during the data analysis phase, and this might potentially have limited external validity to a degree.

To compound this thorny issue Kitwood introduces the idea of “judicious compromise” (2007, p.172) in which the argument is made that the conventional notions of reliability and validity in the context of interviews are redundant, and all interpersonal interactions are valid, they are reflections of valid feelings and ideas at that time. The value of this argument seems to imply that any interview data is completely context specific and has no generalisability.

3.9 Ethical considerations

In its stated principles, the British Educational Research Association (BERA), (2018) declares that there is a need for researchers in the social sciences to act with integrity with regard to their social responsibilities whilst at the same time maximising benefit and minimising harm. The BERA guidelines further state that all education researchers should operate “within an ethic of respect for any person involved in the research they are undertaking" (2018, p.5). The ethical considerations of this study were informed by both those guidelines and the University of Leeds research ethics policy (2015). Before any data were collected for this study, full ethical approval was granted by the University of Leeds research ethics committee. For sight of this approval see Appendix E. What follows is a summary of the main issues that had to be considered before obtaining ethical approval.

3.9.1 Consent

In the first instance, once a staff in a chemistry department had been identified as willing to take part in the study, the head teacher was asked to give consent for data to be gathered in their institution.

After consent had been given for research to be conducted in a school or college, host teachers were apprised of the study and requested to consent to their classes being involved. All students in those classes were then also informed of the purpose and nature of the study: how data would be collected, what it would be, and how it would subsequently be used and stored. This stage was carried out in person by the researcher in order to provide students with a ready opportunity to ask for clarification of any point. So as to minimise any sense of coercion, the students' written consent was sought in instances when the researcher was not present.

No consent was sought for student participation in the research lessons, nor for their completion of the assessment items two weeks after the intervention lesson. This was due to the fact that students in this study would attend, as part of their normal timetable, chemistry lessons and have routine assessment opportunities. It was the view of the University of Leeds research ethics committee that the content and pedagogies of the planned intervention lessons were within the normal variation that a class teacher might routinely use. The questionnaire and group interview phases of data gathering were judged to be outside of the normal routine and expectations of A Level students. Since all students were above the age of sixteen at the time of the study their consent was sought directly. The students were asked for their consent to two things: first, to complete the questionnaire and to allow anonymised data from this to be used in the final thesis and subsequent academic papers and presentations; second, to take part in a group interview where the spoken word was recorded, transcribed and used in this thesis, subsequent academic papers and presentations.

No parental consent was sought for participation of students in the study as all of the participants were above the age of sixteen. However, following guidance on best practice from the University of Leeds Research ethics committee, a letter was provided for the parents and guardians of all participants that informed them of the nature of the study.

The participants were all given an opportunity to have any data provided in the questionnaires and/or group interviews to be withdrawn. A clear time limit of one calendar month following data collection was set, during which requests for such an action to be taken could be made; after that period there would be no right to withdraw any data. Data that was provided in the form of answers to the post-intervention assessment items could not be withdrawn from the study, as this was judged to be a normal part of teaching and learning in A Level Chemistry.

3.9.2 Mitigation of detriment arising from participation

In each phase of the study, all of the students in that phase were working on the same chemistry content. The lesson plans show how the introduction to the new work used the same examples but presented them in different ways, depending upon whether the lesson was for a drama or an examination-style question class. In all three phases, the middle section of the lessons varied by group type. In addition, for Phases 2 and 3, the final section of the lesson involved both the drama and examination-style question classes completing the same sample past examination question.

A Level examinations are considered to be high-stake assessments with grades, in many cases, determining admission to university or future careers. Before conducting the study, it was impossible to know whether or not, overall, the use of one pedagogy over another would benefit the students involved. As a result, in order to mitigate any such scenario in which there was a detrimental effect, once the assessment items had been completed (approximately two weeks following the intervention lessons) the researcher marked the student scripts and returned the individual scores to the host teacher of each of the classes. If there were any concerns about the marks or the manner in which the research had been conducted, the host teacher was then asked to contact the researcher. At that point, if such concerns had been raised, the researcher would offer to re-teach the topic using a pedagogy agreed upon with the teacher. The researcher also offered to provide an additional revision lesson in the term preceding external examinations, should it have felt to have been required. It must also be noted that, over the course of the study, there were two intervention lessons for each student. As these interventions cover only one part of a topic on the overall specifications, there would be minimal potential impact to be had upon the final A Level grades attained by the students.

Due to the fact that being asked to perform in front of their peers can sometimes cause embarrassment or anxiety, steps were taken to minimise this: in the simulation-role-play section of the intervention lessons, students self-selected the groups in which they wished to work (generally friendship groups). Within the simulation-role-play activities, there were also opportunities for group members to carry out less overtly performative tasks, e.g. being a narrator. The decisions regarding which students would take on each role in the simulation-role-play activities were left to students within each group; this was done in order to enable a more authentic lesson approach. Across all of the intervention lessons in the study, only one student, with autism, selected not to take part in the simulation-role-play activities. They were provided with examination-style questions to complete as an alternative and their questionnaire and assessment items were not included in the final dataset.

3.9.3 Data protection

All data were stored securely and in accordance with the requirements and protocols of the University of Leeds research ethics committee. Non-anonymised responses to questionnaires and assessment items, audio recordings, and lists of test scores, including data provided by teachers, e.g. concerning students with special educational needs, were all stored in a locked filing cabinet when not in use. Non-anonymised audio recordings and transcripts of the group interviews were uploaded to a secure portal and recordings deleted from the Dictaphone. In the interim, the recording device was also kept in a locked filing cabinet.

As part of the processing of the data, personal information, test marks, questionnaire responses and group interview inputs were anonymised and encoded.

All hard copies of the data will be disposed of in confidential waste no more than ten years after its collection. Non-anonymised electronic data will be deleted within the same timescale.

Chapter 4
Qualitative and Quantitative Data Analysis

4.1 Overview

The following chapter reports the quantitative and qualitative data analysis for the three phases of the study relating to the main research question: how do student marks in examination questions on organic reaction mechanisms differ depending on whether they have been taught using simulation-role-play or practice examination-style questions? The data for Phases 1 and 2 of the study are presented together, as Phase 2 was a repeat of Phase 1 with minor changes to the intervention lesson. The analysis of that data is presented in two sections: qualitative and quantitative. Phase 3 is reported separately but again involves a combination of quantitative and qualitative data.

Quantitative statistical analysis was performed on data comprising of marks from test scripts that were completed by students during each stage of the study, approximately two weeks after the intervention lessons. These data were coded and statistically analysed in accordance with the framework that was established in Chapter 3 (methodology). The analyses sought to determine whether or not there were differences in test score marks between the two groups (drama vs examination-style question). The data were interrogated with respect to gender, predicted A Level Chemistry grade, A Level subject choices and perceived prior classroom pedagogy in Chemistry lessons. Quantitative analysis was performed on the questionnaire responses that were linked to student perceptions of the use of simulation-role-play to assist in the remembering and understanding of the relevant chemistry, as well as in the preparation for answering examination questions. The associated data derived from the transcripts of the group interviews from across the three phases are also subjected to qualitative analysis.

4.2 Quantitative data analysis for Phase 1

This section aims to answer the following research question: do students' marks in A Level examination questions on organic reaction mechanisms differ, in a statistically significant manner, depending upon whether they have been taught using simulation-role-play or practice examination-style questions? This question is addressed, here, through the statistical analysis of marks awarded to responses to the post-intervention tests administered in Phase 1.

4.2.1 Return rates

Following the initial visits to both groups (drama and examination-style question) all students that were taught by the researcher were requested to complete the same past examination questions on nucleophilic substitution (See appendix B.1). Host teachers were asked not to re-teach any of the material, and to also not teach any further content related to that which was covered by the researcher. They were also asked to hand out the questionnaires and examination questions for completion, during lesson time, approximately two weeks after the researcher had taught the lesson.

Data sets were only included in the analysis if they met certain criteria. Any data sets that were returned with unfinished questionnaires, questionnaires in which the examination questions had not been attempted at all, or that were missing signatures, were not entered into the analysis. Similarly, any data linked to students that were repeating the year was also discarded. The overall return rates are given in the following tables.

Table 4.1 Number of respondents from drama groups in Phase 1

School/college identifier	Number of students in lesson	Number of respondents	Number of respondents entered for analysis
1	13	5	1
2	19	18	16
3	12	12	9
4	11	7	5
5	9	8	7
6	7	7	7
7	24	22	18
8	22	21	18
Total	**117**	**100**	**81**

Table 4.2 Number of respondents from examination-style question groups in Phase 1

School/college identifier	Number of students in lesson	Number of respondents	Number of respondents entered for analysis
1	4	4	4
2	17	17	17
3	15	15	10
4	12	9	8
5	13	13	12
6	7	7	4
7	23	23	20
8	17	17	13
Total	**108**	**105**	**88**

During the intervention visit to School 9, a large proportion of the class were Danish students on an exchange visit, with many of the usual class away in Denmark as part of the same exchange. This unusual situation meant data from this school were removed from the study.

School 10 did not return background data, including predicted A Level grades, or any teacher concern forms. The host teacher at School 10 retired following Phase 1 of the study and so, as a consequence, data pertaining to this school were removed from the study.

4.2.2 Coding personal data from the questionnaire

The data received were from two sources: individual questionnaire responses from students and predicted A Level Chemistry grades from host teachers.

Questionnaire data were encoded in Excel 2013 workbooks.

Prior attainment at GCSE in Chemistry (Science) was not included in the final coding for the following reasons:

i. There was a mixture of single science grades (individual GCSE awards for each one of the sciences, including Chemistry) and dual award grades (Core and Additional) reported. The dual award grade is awarded as an amalgamation of marks across the three sciences, whereas the single Chemistry grade is awarded on the basis of marks obtained only in chemistry.
ii. Whilst the majority of students had been entered for higher tier GCSE papers there were some that had been entered for the foundation tier (this applies to both dual award and single science GCSE awards). The specifications for the different levels of assessment involve differing content for each of the three sciences.
iii. Students doing dual award often did not declare the mark for their additional science GCSE.

Due to the variation in reported prior attainment, it was decided to focus on predicted A Level grades, and these were gathered as a proxy data set. A Level Performance System (Alps) data were gathered for all students in the study. Alps is a data analysis system originally developed at Greenhead College, Huddersfield, in the

1990s. At the time of this study, Alps was used by all of the schools and colleges taking part. These data are the result of statistical comparison of the average GCSE grades for an individual being compared against the DfE national dataset, comprising results from approximately 2,500 schools and colleges in England and over 240 000 students resulting in subject-specific predicted A Level grades (Alps, 2014).

4.2.3 Coding examination question responses from students in Phase 1

All student responses to the test scripts were initially coded using the original mark schemes from the examination boards (AQA, 2018; OCR, 2018; Pearson Edexcel, 2018) which meant that there was a maximum of 17 marks. Some questions required candidates to have completed a number of steps in thinking before they could be awarded a mark. For example, for the first mark in the examination board mark scheme a candidate needs to give three aspects of a nucleophile before being able to gain the mark. In order to establish in detail which aspect(s) of a question each student had a comprehension of, a 'fine-grain' mark scheme was produced resulting in a maximum of 28 possible marks. To reduce the potential for researcher bias, the fine-grain mark scheme was scrutinised by a PhD chemist and an academic science (chemistry) educator. The relationship between the two mark schemes (referred to forthwith as the examination board mark scheme and the fine-grain mark scheme) and the agreed codings is shown in Appendices B.1.1. Results for the coded scripts were entered into an Excel 2013 spreadsheet, a suitable format to be imported into Statistical Package for Social Sciences (SPSS) v23, in which subsequent statistical analysis was carried out. The significance threshold was set at 0.05 ($p \leq 0.05$).

4.2.4 Inter-marker reliability

A sample of nineteen sets of test scripts were selected and marked independently by the researcher and an academic science (chemistry) educator, with subsequent coding then applied in accordance to the guidance referred to above. An excellent degree of reliability was found to exist between the two markers for the sample of the examination questions. The inter-class correlation for the total marks awarded was 0.98, with a 95% confidence interval from 0.96 to 0.99 ($F(18,18) = 62.84$, $p < 0.001$), and for the total fine-grained marks awarded this correlation was 0.99, with a 95% confidence interval from 0.98 to 1.00 ($F(18, 18) = 123.25$, $p < 0.001$).

4.3 Statistical analysis of test script responses

This section shows the data analysis carried out in order to answer the research question how do student marks in examination questions on organic reaction mechanisms differ depending upon whether they have been taught using simulation-role-play or practice examination questions?

4.3.1 How comparable are the two groups in terms of predicted A Level Chemistry grades?

Kolmogorov-Smirnov tests in tandem with visual inspection of histograms led to the determination that Phase 1 data did not violate the core assumptions of parametric analysis, i.e. there was no major skew or kurtosis in the distributions. Results are shown in Table 4.3 below.

Table 4.3 Results of Kolmogorov-Smirnov test for normality, Phase 1

	Group	**Kolmogorov-Smirnov**		
		Statistic	**df**	**Sig.**
Total mark on examination question /17	Drama	0.10	81	0.05
	Examination-style question	0.09	89	0.07
Total mark on examination question /28	Drama	0.08	81	0.20
	Examination-style question	0.09	89	0.07

Having established the fact that the data were distributed normally it was important from the outset to see whether the two groups (drama and examination-style question groups) were of similar ability before going ahead to analyse the data further. An independent samples t-test was conducted to compare predicted A Level grades in the drama class group and examination-style question class group (whole cohort). There was a significant difference in the scores. For the drama group (M = 3.77, SD = 1.19) and the examination-style question group (M = 3.34, SD = 1.18): $t(168) = 2.36$, $p = 0.02$. This means that the two groups are not matched on this measure of predicted grade: there is a statistically significant difference, with the examination-style question group having been predicted higher grades. Statistical analysis needs to take this into account by using predicted A Level grades as a covariant.

4.3.2 Do the marks between the drama and examination-style question groups differ significantly from one another?

In order to answer this question, the test responses were analysed using total marks for each student according to both the examination board mark scheme and the fine-grain mark scheme, as well as to selected individual fine-grain questions.

Examination board mark scheme

A one-way ANCOVA analysis was conducted to determine whether there was a statistically significant difference between the overall drama and examination-style question groups' scores obtained using the examination board mark scheme, controlling for predicted A Level grade.

There was no statistically significant difference between the marks awarded to the two groups (drama and examination-style question groups) after controlling for predicted A Level grade: $F(1,169) = 0.18$, $p = 0.68$.

Fine-grain mark scheme

A one-way ANCOVA analysis was conducted to determine whether there was a statistically significant difference between the drama and examination-style question group overall scores obtained using the fine-grain mark scheme, controlling for predicted A Level grade.

There was no statistically significant difference between the marks awarded to the two groups (drama and examination-style question groups) after controlling for predicted A Level grade: $F(1,169) = 0.11$, $p = 0.75$.

Specific fine-grain questions

A number of fine-grain questions were selected for further analysis. (For details on how these were selected see Chapter 3, the methodology chapter.) Rather than having recall or descriptive answers, all of these questions required students to actually draw reaction mechanisms.

Responses to each of these questions were analysed using chi-squared (χ^2) tests, the results of which are presented in Table 4.4 below.

Table 4.4 Chi-squared analysis of results for individual fine-grain questions in Phase 1

Fine-grain question number	Group	Mark awarded		*N*	$\chi^2(1, N = 170)$	*p*
		1	**0**			
5	Drama	47	34	81	2.00	0.16
	Examination-style question	42	47	89		
6	Drama	37	44	81	0.15	0.71
	Examination-style question	38	51	89		
7	Drama	58	23	81	3.25	0.07
	Examination-style question	74	15	89		

Fine-grain question number	Group	Mark awarded		*N*	χ^2(1, *N* = 170)	*p*
		1	0			
8	Drama	41	40	81	0.08	0.75
	Examination-style question	47	42	89		
9	Drama	42	39	81	0.18	0.68
	Examination-style question	49	40	89		
11	Drama	10	71	81	2.43	0.12
	Examination-style question	19	70	89		
12	Drama	18	63	81	1.83	0.18
	Examination-style question	28	61	89		
13	Drama	14	61	81	1.033	0.31
	Examination-style question	21	68	89		

In all cases there are no statistically significant differences between the scores obtained irrespective of the group (drama class or examination-style question class) for any of the selected fine grain questions.

4.4 Analysis of test script responses by factors

Test scores were analysed with respect to gender, predicted A Level Chemistry grade, number of STEM subjects in addition to chemistry and perceived prior classroom pedagogies.

4.4.1 Is gender a significant factor behind any differences between test marks obtained by the two groups?

For both groups, test scores given in accordance to both the examination board mark scheme and the fine-grain mark scheme were analysed in relation to gender.

Examination board mark scheme

Marks awarded using the examination board mark scheme were analysed to see whether gender was a significant factor in either the drama or the examination-style question groups.

Table 4.5 Descriptive statistics for marks obtained by male and female students in the drama group and the examination-style question group when marks were awarded in accordance to the examination board mark scheme

Group	Gender	Mean	Standard Deviation
Drama	Male	8.05	4.23
	Female	8.20	3.29
Examination-style question	Male	7.21	4.03
	Female	9.04	3.69

A two-way ANCOVA was conducted to determine whether there was a statistically significant difference between the drama and examination-style question group test scores, using the examination board mark scheme, with respect to gender. The two independent variables were teaching group (drama vs examination-style question) and gender (male vs female).

There was no significant main effect of gender ($F(1, 166) = 2.84$, $p = 0.09$) nor was there a significant interaction between gender and group ($F(1, 166) = 2.07$, $p = 0.15$).

There is not a statistically significant difference in test scores obtained using the examination board mark scheme between the genders across the sample as a whole nor is there an effect of gender in one group and not the other: the effect of gender was similar in both drama and examination-style question group.

Fine-grain mark scheme

Similar patterns were identified when the same tests were carried out on the marks given in accordance to the fine-grain mark scheme.

Table 4.6 Descriptive statistics for marks obtained by male and female students in the drama group and the examination-style question group when marks were awarded in accordance to the fine-grain mark scheme

Group	Gender	Mean	Standard Deviation
Drama	Male	14.20	6.58
	Female	14.66	5.40
Examination-style question	Male	13.02	7.21
	Female	15.98	6.03

A two-way ANCOVA was conducted to determine whether there was a statistically significant difference in marks between the drama and examination-style question group scores with respect to gender when using the fine-grain mark scheme. The two independent variables were teaching group (drama vs examination-style question) and gender (male vs female).

There was no significant main effect of gender ($F(1, 166) = 3.07$, $p = 0.08$) nor was there a significant interaction between gender and group ($F(1, 166) = 1.64$, $p = 0.20$).

There was no statistically significant difference in scores (obtained using the fine-grain mark scheme) between the genders across the sample as a whole, nor is there an effect of gender in one group and not the other: the effect of gender was similar in both drama and examination-style question group.

4.4.2 Are predicted A Level Chemistry grades a significant factor behind differences between test marks obtained by the two groups?

For both groups, test scores given in accordance to both the examination board mark scheme and the fine-grain mark scheme were analysed in relation to predicted A Level Chemistry grades.

Examination board mark scheme

In order to determine whether there were any differences between the two groups (drama and examination-style question) in terms of the performance of students with varying predicted grades, two categories were created based upon predicted A Level grades: A*-B and C-E respectively. These bandings were selected since the unified mark schemes for A Level examinations allocate ten marks between the top and bottom mark of any single grade, therefore the range of marks between the highest and lowest score in both bands are equal.

Table 4.7 Descriptive statistics for marks obtained by students from each predicted A Level Chemistry grade banding in the drama group and the examination-style question group, when marks were awarded in accordance to the examination board mark scheme

Group	Predicted A Level Chemistry grade	Mean	Standard Deviation
Drama	A*-B	8.60	3.66
	C-E	7.66	3.84
Examination-style question	A*-B	8.85	3.53
	C-E	7.09	4.35

A two-way ANOVA was conducted to determine the impact of predicted A Level Chemistry grades on scores. The two independent variables were the teaching group (drama vs examination-style question) and the predicted A Level Chemistry grade. There was a main effect of predicted A Level Chemistry grade. This means that students with higher predicted A Level Chemistry grades did better, to a statistically significant degree, than those with lower predicted A Level Chemistry grades: $F(1, 166) = 5.244$, $p = 0.025$, irrespective of their group.

There was no interaction between predicted A level Chemistry grade and group ($F(1, 166) = 0.49$, $p = 0.49$). This indicates that the difference between ‘high’ and ‘low’ performers does not, itself, vary to a statistically significant extent between the drama and examination-style question groups.

Fine-grain mark scheme

As above, two groups were created based on predicted A Level Chemistry grades: A*-B and C-E respectively.

Table 4.8 Descriptive statistics for marks obtained by students from each predicted A Level Chemistry grade banding in the drama group and examination-style question group, when marks were awarded in accordance to the fine-grain mark scheme

Group	Predicted A Level Chemistry grade	Mean	Standard Deviation
Drama	A*-B	15.13	5.73
	C-E	13.76	6.20
Examination-style question	A*-B	15.85	6.12
	C-E	12.54	7.27

A two-way ANOVA was conducted to determine the impact on predicted A Level Chemistry grades on scores achieved when using the fine-grain mark scheme. The two independent variables were the teaching group (drama vs examination-style question) and the predicted A Level Chemistry grade. There was a main effect of predicted A Level Chemistry grade. Students with higher predicted A

Level Chemistry grades did statistically better than those with lower predicted A Level Chemistry grade: $F(1, 166) = 5.7$, $p = 0.02$.

There was no interaction between predicted A level Chemistry grade and group: $F(1, 166) = 0.98$, $p = 0.32$. This indicates that the difference in performance between ‘low’ and ‘high’ performers does not significantly differ between the drama and examination-style question groups.

4.4.3 Is there a correlation between test marks and the number of STEM subjects students are studying?

The majority of students (n(drama group) = 69, n(examination-style question group) = 72) reported taking four subjects in the first year of their A Level studies and these were used in the following section; students taking either three or five subjects were, by contrast, excluded from this analysis. Pearson product-moment correlation coefficients were computed, controlling for predicted A level grade using partial correlations, for both the drama group and the examination-style question group with respect to their overall scores for both the examination board mark scheme and the fine-grain mark scheme.

Table 4.9 Pearson product-moment correlation coefficients for the relationship between the number of STEM subjects taken in addition to chemistry and the overall test scores, awarded in accordance to both the examination board and the fine-grain mark schemes, for both the drama and the examination-style question group

Mark scheme	Group	*n*	*r*	*p*
Examination board	Drama	69	0.35	0.77
	Examination-style question	72	0.11	0.34
Fine-grain	Drama	69	0.01	0.95
	Examination-style question	72	0.03	0.83

For both the drama and the examination-style question group, no statistically significant correlation was found between the test marks accorded by either mark scheme and the number of STEM A Levels being studied in addition to chemistry.

4.4.4 Is there a correlation between test marks and prior classroom pedagogy?

In order to see whether there was a correlation between prior perceived classroom experiences in chemistry and the mark scored in the test, questionnaire data were used to produce two composite groups: traditional pedagogy and interactive pedagogy. Students reported how many times, in the four weeks leading up to their completion of the questionnaire, they had experienced specified teaching pedagogies in their chemistry lessons. These reported values were used to produce two groups: the traditional pedagogy group and the interactive pedagogy group. Composite scores for each student were calculated using the formulae below and these values were subsequently used in statistical analyses:

- Traditional pedagogy score = mean of examination questions, presentations and written work values reported in the questionnaire.
- Interactive pedagogy value = mean of interactive activities such as card sorts, experimental work and group discussion values reported in the questionnaire.

For each of these pedagogy groups the relationship between the pedagogy group scores and test scores for both the examination board mark scheme and fine-grain mark scheme were calculated using Pearson product-moment correlation, controlling for predicted A-level grades using partial correlations.

Table 4.10 Pearson product-moment correlation coefficients, controlling for predicted A Level grades, to assess the relationship between the perceived amount of prior teaching pedagogy and test scores obtained when marks were awarded in accordance to both the examination board and the fine-grain mark schemes

Mark scheme	**Group**	**Classroom pedagogy prior to intervention**	***n***	***r***	***p***
Examination board	Drama	Traditional	78	0.09	0.45
		Interactive	78	0.02	0.83
	Examination-style question	Traditional	78	0.04	0.71
		Interactive	86	0.16	0.13
Fine-grain	Drama	Traditional	78	0.04	0.75
		Interactive	78	0.04	0.71
	Examination-style question	Traditional	86	0.09	0.13
		Interactive	86	0.14	0.20

For each group (drama and examination-style question) there was no statistically significant correlation between the test scores, as obtained by either the examination board mark scheme or the fine-grain mark scheme, and the perceived prior classroom pedagogy.

4.5 Quantitative data analysis for Phase 2

This section answers the following research question: Do students' marks in A Level examination questions on organic reaction mechanisms differ, in a statistically significant manner, depending on whether they have been taught using simulation-role-play or practice examination-style questions? It does this through the statistical analysis of marks awarded to the post-intervention tests in Phase 2.

4.5.1 Context

Four schools were involved in this phase of the study, resulting in a smaller sample size than Phase 1: *n*(drama class) = 32, *n*(examination question class) = 34. In response to comments made during the Phase 1 group interviews, the lessons that were taught in Phase 2 were slightly modified from those of Phase 1. Details of these changes are given in Chapter 3 (methodology). The test papers, consisting of the same questions completed in Phase 1, minus the question with ammonia as a nucleophile, were coded in a similar manner as for Phase 1 of the study and the analysis was also performed using SPSS v23.

Kolmogorov-Smirnov tests in tandem with visual inspection of histograms led to the assumption that Phase 2 data did not violate the core assumptions of parametric analysis, i.e. there was no major skew or kurtosis in the distributions.

Table 4.11 Kolmogorov-Smirnov tests for normality for Phase 2 data

	Group	**Kolmogorov-Smirnov**		
		Statistic	**df**	**Sig.**
Total mark on examination board mark scheme/17	Drama	0.11	32	0.20
	Examination-style question	0.16	34	0.04
Total mark on fine-grain mark scheme /28	Drama	0.12	32	0.20
	Examination-style question	0.17	34	0.01

4.5.2 How comparable are the groups in terms of students' predicted A Level Chemistry grades?

An independent two-tailed t test demonstrated that, unlike predicted A Level Chemistry grades in Phase 1, there was no statistically significant difference between the predicted grades of the drama group (M = 3.25, SD = 0.95) and the examination-style question group (M = 3.00, SD = 0.98): t(64) = 1.05, p = 0.30. This means that the two groups are matched on this measure of predicted A Level Chemistry grade and there is no need to use this measure as a covariant, unlike Phase 1 data analysis.

4.5.3 Are there significant differences between the marks obtained by students in each of the drama and examination-style question groups?

Statistical analysis was performed on the data in order to ascertain whether there was a significant difference between the performance of students across the two groups.

Examination board mark scheme

Independent two-tailed t tests were carried out for the test marks obtained from marking using the examination board mark scheme for the drama group (M = 8.84, SD = 3.76) and examination-style question group (M = 9.85, SD = 3.56): $t(64) = -1.12$, $p = 0.27$. There is no statistically significant difference between the two groups in terms of marks accorded by the examination board mark scheme.

Fine-grain mark scheme

Independent two-tailed t tests were carried out for the test marks obtained from marking using the fine-grain mark scheme for the drama group (M = 15.63, SD = 6.34) and examination-style question group (M = 17.97, SD = 5.80): $t(64) = -1.57$, $p = 0.12$. There is no statistically significant difference between the two groups in terms of marks accorded by the fine-grain mark scheme.

Specific fine-grain questions

The same fine-grain questions used in Phase 1 were analysed using chi-squared (χ^2) tests.

Table 4.12 Chi-squared analysis results for individual fine-grain questions in Phase 2

Fine-grain question number	Group	Mark awarded		*N*	χ^2(1, *N* = 66)	*p*
		1	0			
5	Drama	12	20	32	0.19	0.66
	Examination-style question	11	23	34		
6	Drama	12	20	32	0.04	0.85
	Examination-style question	12	22	34		
7	Drama	17	15	32	0.06	0.80
	Examination-style question	17	17	34		
8	Drama	16	16	32	2.12	0.15
	Examination-style question	11	23	34		
9	Drama	18	14	32	2.92	0.09
	Examination-style question	12	22	34		
11	Drama	3	29	32	3.34	0.07
	Examination-style question	0	34	34		
12	Drama	9	23	32	1.78	0.19
	Examination-style question	5	29	34		
13	Drama	6	26	32	0.04	0.85
	Examination-style question	7	27	34		

In all cases there are no statistically significant differences between the scores irrespective of the group for any of the questions marked using the fine grain mark scheme.

4.6 Qualitative and quantitative analysis for Phases 1 and 2 of the study

What follows are two strands of analysis: quantitative analysis of questionnaire data relating to affective responses and a summary of the main themes that emerged from the group interviews, and the way in which these themes have a relevance to the theoretical underpinning discussed earlier in this thesis in Chapter 2. These include learning theory, the use of macro, sub-micro and symbolic representations in science, and the use of embodied learning and visualisations to construct mental models that subsequently contribute to expressed models. The structure of this section reflects the following three research questions:

i. How do students perceive the use of simulation-role-play in their recall of organic reaction mechanisms?

ii. How do students perceive the use of simulation-role-play in their understanding of organic reaction mechanisms?

iii. How do students perceive the use of simulation-role-play in preparing them for answering examination questions relating to organic reaction mechanisms?

4.6.1 Drama and Recall

A visual inspection showed that the responses in the questionnaire to the statement “I found the chemistry in this lesson easy to remember” for both Phases 1 and 2, demonstrated kurtosis; as a result, the data were treated as non-parametric for statistical analysis. Descriptive statistics of that analysis are presented in Table 4.13.

Table 4.13 Descriptive statistics for responses to the statement "I found the chemistry in this lesson easy to remember", in Phases 1 and 2

Group	*n*	Median	Standard deviation
Phase 1 drama	80	2.85	0.78
Phase 1 examination-style question	84	2.44	0.59
Phase 2 drama	31	2.48	0.57
Phase 2 examination-style question	33	2.52	0.67

Phase 1 data, a Mann Whitney U test indicated there was a statistically significant difference between the scores of students in the drama class (*Mdn* = 2.85) and those of the students in the examination-style question class (*Mdn* = 2.44). The results of the test were U = 2275, $p = 0.00$, with the examination-style question group reporting that the chemistry was easier to remember when compared to the responses from the drama group.

For Phase 2 data, a Mann Whitney U test indicated there was no statistically significant difference between the scores of students in the drama class (*Mdn* = 2.48) and those of the students in the examination-style question class (*Mdn* = 2.52). The results of the test were U = 482, $p = 0.66$, with neither group having thought that the chemistry was easier to remember than did the other.

This section looks at the different aspects of the lessons that were remembered in the post-intervention group interviews and considers what connections these might have to the recall of the relevant chemistry. In the tables below, selected quotations have been used to exemplify the theme. The unique identifier for the student speaking the words is in the left column, the section of relevant text is in the middle column, and the coding reference is in the right column.

Students involved in this study reported a number of different aspects prompting their recall of events from their internal mental models, the assumption being made that a mental model must have been constructed in order for recall to take place.

Student 1.1.b.d identified the role of humour in helping them recall what happened in the drama lesson, as can be seen in the comment cited below:

1.1.b.d	I preferred watching it, but I can also remember part of the scripts because some of them were quite funny. So the funny parts I can remember. But like the more wordy parts, I find a little bit harder….	1.2

There were a number of specific examples of the use of humour that were cited. These included:

1.1.b.d	Mr X [teacher] dropping the little balls after he had stuck it on [laughter] and then couldn't find them again.	1.2
2.5.p.d	I remembered a lot, when we came up with the storyline, sort of for the erm, for example, 2.5.a.d made a little joke about them divorcing 2.1.e.d and 2.5.a.d because erm… as a representation of electrons moving in between.	1.2

The role of humour in the classroom has been well studied, with the work of Banas et al. (2011) being one example of this. However, whilst many claims have been made with regard to the affective domain, there has been mixed reporting of the impact of humour upon learning: some, such as Wanzer and Frymier (1999), argue that the use of humour in the classroom has a positive impact upon learning; others, such as Houser, Cowan and West (2007), posit that humour in the classroom has no effect upon learning. Further to that, one recent research project concluded that the use of humour impacted adversely upon learning (Bolkan, Griffin and Goodboy, 2018). It is clear from the student text examples above that humour allowed students to recall events in the lessons; this is, however, just recollection of events, not of chemistry. The examples below begin to illustrate how some of the recalled events assisted in the students being able to link the drama to different aspects of the relevant chemistry.

4.6.2 Movement

A common theme present in all of the group interviews from the drama lessons was the remembrance of certain aspects relating to the macro (drama) level (Johnstone, 1991). Physical movement and the use of props appear to have been useful memory aids, linking to the work on embodied learning (see Chapter 2, the literature review, for more information). The following three examples evidence increasingly sophisticated levels of recollection.

The first example is very vague with no detail:

1.5.h.d	I remember having stuff stuck on me [laughter] and [being] pulled around the room [laughter]	1.1

The second example implies there is a link between the movement and chemistry, although it is a very vague link:

2.4.j.d	Yes, I remember with the kit, you had to put it round your neck and you'd be an individual, whatever you were. [laughs] And you'd do like the additions and substitutions using people.	1.1

The third example exemplifies a situation in which a student is able to relate specific movements to a specific part of the relevant chemistry, albeit a small part of the overall process, and to demonstrate macro to sub-micro links:

2.1.b.d	I think that actually doing the drama actually helped me remember that the arrows actually attacked the delta positive or delta negative.	1.1
Researcher	So, do you have an image in your head of that happening?	
2.1.b.d	Yes, especially with moving the electrons from the negative part as well. I think it was a good way to actually see what's happening, what you're writing down on paper in a different format.	

In order to become a competent chemist, it is recognised there is a need for the student to be able to link the macro and sub-micro aspects of the relevant chemistry together (Johnstone, 1991; Jaber and BouJaoude, 2012). There were examples indicating that students in the drama classes were able to do this. This is made clear in the following excerpts from the transcripts, in which students are linking specific aspects of the simulation-role-play to the related chemistry.

The movement of electrons is a key principle in interpreting organic reaction mechanisms, (Kermack and Robinson, 1922; Morrison and Boyd, 1959; Grove, Cooper and Rush, 2012), so being able to link the relevant macro and sub-micro aspects together is crucial if drama is to be an effective pedagogy. Each felt ball represented an electron, and the growing sophistication of comments below indicate an awareness of the impact of different representations, depending upon their context. For example, students identified that two felt balls on the label of an atom represented a lone pair of electrons, while those same felt balls represented a single covalent bond when fastened to a ruler held between two atoms (individual actors with a label bearing an atomic symbol).

1.7.b.d	I remember putting signs on us to represent different, erm, things that were involved in the reaction and then using little cotton balls to represent electrons and then transferring them by taking them off and placing them on other people that were wearing the signs too… they represent the movement and what happens during the reactions.	1.3

1.4.c.d	I think the most things that stick out for me is the electrons which were done by the little ball things and that made it easier to remember where they were going and which times.	1.3
Researcher	OK. Lovely. Can anyone remember the difference between when the, those little electron balls were together like that or they were on the ruler? What was that about?	
1.4.e.d	If they were on the ruler they were in a bonded thing, but if they weren't in the bond they were in the atom.	
Researcher	OK. Thank you. 1.4.a.d? Anybody remember anything else.	
1.4.a.d	I remember walking round the room quite a bit.	
Researcher	Walking round the room, doing lots of useful things or just walking round the room?	
1.4.a.d	Walking round the room and holding people's hands and rulers and moving stuff and velcroing bits and pieces.	
Researcher	OK and do you remember that being useful in terms of chemistry or just you were walking round doing stuff.	
1.4.a.d	I think it helped to sort of reinforce that basic principle of sort of, after doing it, it is sort of in your head roughly, and I remember what was going on by thinking about other people in your head.	
2.5.p.d	They [pompoms] were stuck in different places weren't they, cos as well as pairs they were on the sheet whereas in bonds they were on rulers.	1.3

4.6.3 Linking two-dimensional and three-dimensional representations: macro and sub-micro

In order to be able to answer examination questions there is a need for the student to use their learning to engage with symbolic two-dimensional representations. In this study the symbolic representations are the questions and answers to the examination questions where students are often been asked to write or interpret equations. These questions can bring with them the associated challenges of working with two-dimensional molecular representations of three-dimensional structures. The latter has been identified as a barrier to student construction of reaction mechanisms (Ellis, 1994). The simulation-role-play activities provide a form of macro three-dimensional representation. It has been proposed that if a student can move with fluency between these representations this would assist with their being able to make sense of the relevant chemistry (Johnstone 1991, 2010; Grove, Cooper and Rush, 2012). The examples below illustrate that some students were able to link the three-dimensional dramatic representations to the two-dimensional representations made on paper.

1.5.h.d	You're so used to being, to doing a 2D, I think the 3D just helped secure the understanding of what was going on and then looking at the 2D so you could actually write it down and… revise it.	1.4
2.5.p.d	Yes, having a physical 3D representation of something rather than it just being lines on a board made it easier to see what was moving where and why and all of that.	1.4
2.1.c.d	I think it helps me remember where the electrons attacked or where, like the electrons moved because we physically moved them and we also got to learn if certain molecules like, or certain atoms in molecules where its delta positive by negative? […] we had to like Velcro, stick it on, which part was negative or positive, and like how they attacked and sort of…. So, it helped me remember that more than anything.	1.4

4.6.4 When thinking about the lesson retrospectively, what chemistry did the students remember?

When asked directly whether the drama helped with remembering the chemistry (as opposed to what was remembered of the lesson), students articulated a range of thoughts. These ranged from being able to link the movement of people to the movement of arrows in the mechanisms, i.e. linking macro and sub-micro aspects of the relevant chemistry through the use of embodied learning, through to concerns around how the drama can be applied to the theory.

1.5.a.d	It is a way of remembering which way the arrows go, and to which way you move people around.	2.1
1.1.a.d	I think I can like visually remember it, like I can remember what we did. But it's harder to remember like how to apply it. But I do remember like visually, like, doing stuff rather than just sitting and writing. So, it was more of an active lesson.	2.1
1.5.h.d	Erm I agree that it was a fun way to learn the chemistry but I think it would be, I think… I don't think I remembered it as well using the drama. I think it was a more enjoyable way to learn because you're moving about and you're actually interacting but I think questions and things are a more solid way for me to learn, and stuff, than the drama.	2.1
2.1.f.d	It didn't really help me. Well personally I didn't remember it that well, I don't know why I think it was just quite a new thing. I didn't remember it well after the lesson, I had to go over it quite a few times and hopefully I can remember it a bit better now.	2.2

4.7 Drama and understanding

A visual inspection found the responses given to the statement in the questionnaire "I found the chemistry in this lesson easy to understand" for both Phases 1 and 2, demonstrated kurtosis; as a result, the data were treated as non-parametric for statistical analysis. The descriptive statistics are presented in Table 4.14.

Table 4.14 Descriptive statistics for Phase 1 and Phase 2 responses to the statement "I found the chemistry in this lesson easy to understand."

Group	***n***	**Median**	**Standard deviation**
Phase 1 drama	80	2.25	0.70
Phase 1 examination-style question	87	1.97	0.62
Phase 2 drama	31	2.10	0.47
Phase 2 examination-style question	34	2.00	0.55

For Phase 1 data, a Mann Whitney U test indicated there was a statistically significant difference between the scores of students in the drama class *(Mdn* = 2.25) and those of the students in the examination-style question class (*Mdn* = 1.97). The results of the test were U = 2726, *p* = 0.01, with the examination-style question group reporting that they found that the chemistry was easier to understand more than did the drama group.

For Phase 2 data, a Mann Whitney U test indicated there was no statistically significant difference between the scores of students in the drama class (*Mdn* = 2.10) and those of the students in the examination-style question class (*Mdn* = 2.00). The results of the test were U = 470, *p* = 0.30, with neither group having thought that the chemistry was easier to understand than did the other.

This section presents the emergent themes relating to student perceptions of the success of simulation-role-play as an aid to their understanding of the relevant chemistry.

4.7.1 Visual representations

Drawing on the literature, Kegan (2018) talks about *what* we know and *how* we know as being two different aspects of learning. Kegan's former category has parallels with Hattie and Donoghue's (2018) factual and content driven surface learning, while Kegan's *how* category parallels Hattie and Donoghue's notion of a deep learning that is integrated and relational. Deep, *how*, learning is the learning that is linked to understanding as opposed to surface recall.

There were comments in the group interviews supporting the notion that simulation-role-play gives a visual aid to support the understanding of chemistry.

1.7.b.d	I particularly thought the reaction mechanism, I thought it was actually quite helpful to visually see where things were going. So, you could see the electrons moving from one thing to another thing and you could just see that directly and I think that helps quite a lot [with understanding], that actual visual representation.	3.1
2.1.g.d	I think when we write out the mechanisms with our teacher and draw all the arrows it's quite hard to visualise it, like understand what's happening. So, when we did the drama it was quite good to really *understand* what's happening and *why* the arrows go where they do.	3.1
2.1.g.d	I think they complement [drama and examination questions] each other really well so I wouldn't want to do just examination-style questions or just drama. I think that in exam conditions you'd probably refer back to exam questions but in developing your understanding in lessons the drama is really helpful.	5.7
1.5.b.d **1.5.d.d** **1.5.b.d**	Because watching the 3D you were sort of…because you were doing each step by step, because you were watching it happen, you could sort of see how it happened and *why* it happened. Because eventually you had the full 2D copy which you could write down but you knew why things were going there because they were explained via the script of why they were doing it. So rather us write 'that's the mechanism, that's *what* happened learn it', you sort of gained *why* it happens and… [student interrupts] Yes, it helps you remember it more. Because you can see the two, the 3D is basically going into the 2D step by step, that's what I found quite useful.	3.2b

4.7.2 Is simulation-role-play alone enough to answer examination questions?

There were statements that acknowledged that while simulation-role-play may be useful in understanding chemistry further consolidation would be needed in the form of notes and/or practice examination questions. Hattie (2008) reported that deliberate practice has a Cohen's D value of + 0.79, indicating that if the assessment method is written questions then repeat practice of them is a useful strategy, following an initial introduction to the topic via simulation-role-play. These ideas are exemplified in the two sets of student comments:

1.5.b.d **1.5.d.d**	Erm… I think it [drama] helps you to make sure you fully understand it [the chemistry] with the exam questions, but I think to sort of… help you understand it the drama is good but then you definitely need the exam questions Yes, I think like the drama starts off your understanding but you need the exam questions to make sure that it sticks in your head.	3.2c
1.1.b.d	I think I learn a lot by physically writing stuff. So, in lesson when we physically write stuff that's like my first set of notes and like, I like to go over stuff and I suppose with drama it's harder to then replicate it. So I did… I enjoyed it for maybe like a first run through but then it's hard to replicate, like when you revise and like to follow on. So yes, I do like to have physical something in front of me. But it, it did help the workings of it. You could understand how it actually worked rather than just writing so….	3.2c

One member of a group felt strongly that simulation-role-play had not helped with their understanding because of the confusion when the script was enacted, indicating a need to be sure that if this pedagogy is used it needs to be well-practiced:

1.7.d.d	I didn't think it was very useful because the people at the front didn't really know what was going on. So, and they were sort of anticipating what they should be doing so they were like putting electrons down and then they had to like put them back. So, I thought it was quite confusing.	3.2a

4.8 Drama and the answering of examination questions

A visual inspection found that the responses given to the statement in the questionnaire “Using drama/examination-style questions in this lesson helped me to complete the examination questions (the questionnaire was differentiated to ensure students were presented with only the pedagogy they had experienced) for both Phases 1 and 2 demonstrated kurtosis. As a result of this, the data were treated as non-parametric for statistical analysis. The results are presented in Table 4.15.

Table 4.15 Descriptive statistics for Phase 1 and Phase 2 responses to the statement “Using drama/examination-style questions in this lesson helped me to complete the examination questions”

Group	***n***	**Median**	**Standard deviation**
Phase 1 drama	77	2.81	0.72
Phase 1 examination-style question	79	2.08	0.64
Phase 2 drama	32	2.38	0.66
Phase 2 examination-style question	34	1.79	0.59

For Phase 1 data, a Mann Whitney U test indicated there was a statistically significant difference between the scores of students in the drama class (*Mdn* = 2.81) and those of the students in the examination-style question class (*Mdn* = 2.08). The results of the test were U = 1454, $p = 0.00$, with the students in the examination-style question group reporting that they felt their lessons were more helpful in preparing them to answer examination questions than their drama group peers did.

For Phase 2 data, a Mann Whitney U test indicated there was a statistically significant difference between the scores of students in the drama class (*Mdn* = 2.38) and those of the students in the examination-style question class (*Mdn* = 1.79). The results of the test were U = 306, $p = 0.00$, with the students in examination-style question group reporting that they felt their lessons were more helpful in preparing them to answer examination questions than their drama group peers did.

Student responses to examination questions will ultimately determine the grades they are awarded. This is reflected in this section. Some students reported that they had found simulation-role-play useful in helping them answer examination test questions and, although there were examples of how simulation-role-play had been used to support answering these questions, there were many comments of a much more pragmatic nature. There was a focus from some students on what they perceived as being the easiest way to gain marks, even to the point of just memorising work, without necessarily understanding the underlying chemistry.

4.8.1 The recollection of drama as an aid when answering examination questions

When asked whether recollection of drama from the lessons had assisted with the answering of examination questions, it emerged that some students had indeed used the drama as a visual prop to help answer them. It appears that, in order to recall necessary information, some of the students drew upon mental models that incorporated their own movements in the drama lessons. This is in line with the work of Bruun and Christiansen (2016) who reported a clear link between the understanding of scientific concepts and embodied learning. The comments presented below exemplify the type of comment relevant to this section:

2.4.j.d	Yes, so when I see a question on it [a reaction mechanism] I do think of a drama lesson of us standing there doing the activity, you know, swapping about lone pairs and everything. So it does…. [help answer exam questions]	5.11
2.4.g.d	I was a nucleophile during my drama and I remember moving around during the reaction and that has provided me with cues whenever I answer my exam questions, I remembered that I moved around and that provided the cue for actually answering the exam questions.	

In the following two examples, students were able to both visualise sections of the dramatic enactment, including the roles of others, and also claim to have used these to assist in answering the examination questions. The actual movement in the simulation-role-play has supported the formation of a visual mental model. This seems to support Ganis, Thompson and Kosslyn (2004), who reported that the recall of a visual mental image uses 90% of the same sections of the brain as actually viewing an object or event.

1.1.b.d	Erm… just like, like literally visualising when you actually did it. Like with the… someone being each part, like visualising the mechanism.	5.5
1.1.a.d	The delta signs.	
1.1.b.d	Oh yes, like all the signs were on and like moving it. So, it was kind of good to visualise it [when doing the exam questions].	
1.7.b.d	Yes. I think erm… it's kind of like a memory jog [when answering exam questions] in a way because I think 'oh this was moved here by so-and-so, they moved this, I remembered them doing that' erm and that kind of helps with the whole concept of the movement of electrons and things like that.	5.5

In the first excerpt given below, a student states that, when answering examination questions, they were able to use the dramatic experience of reaction mechanisms to internally visualise an answer and to subsequently use this mental model to inform their written response. In doing so, they linked macro and symbolic aspects of the chemistry together, a skill that is necessary for competent scientists (Kolari and Savander-Ranne, 2004). The second student appeared to use a similar strategy initially but as they became more familiar with the examination questions, they were able to work purely at the symbolic level; this links to Hattie's research on the role of practice (Hattie, 2008).

Researcher	So, when you were doing the exam questions did you think about the little pompoms or something else?	5.8
1.4.e.d	No, I thought about them [pompoms] and then sort of thinking about that in my mind helped me when I was writing down [answers to exam questions] to sort of go over it, yes, they moved there, rather than just sort of going straight to it [the exam question].	
Researcher	Right, okay. So, did anybody else visualise what had happened in the lessons when they were actually doing the exam questions, or were you focused just on the paper itself?	
1.4.c.d	To start with, like at the start of doing the exam questions, but by the last one I had started to actually visualise the reaction rather than the actual lesson.	

Although some students were confident in their ability to move straight from the drama to answering examination questions, others felt the dramatic experience needed to be supplemented with further work, including the practising of examination questions. For these respondents it seems that the use of simulation-role-play provided an appropriate introduction to the topic, but one that needed consolidation before they would feel confident to answer examination questions.

1.5.b.d	I think that I wouldn't have been able to do them [exam questions] properly if I hadn't revised the topic after. But if it's a lesson and then, you just tried to remember from that [answering examination questions], then it wouldn't be enough.	5.6
1.5.a.d	Definitely need extra. You sort of get, get… it starts your understanding process but then it needs to be reconsolidated with looking through the book and basically, just writing them out and out and out until you know to do them [exam questions] as fast as you can do them.	5.6
2.5.i.d	I think it would be easy at the beginning to link the drama to the reaction mechanisms but later on I found that I was relying more on the reaction mechanisms I'd already written down, that's just how I learn.	5.9

4.8.2 Method of assessment

A more pragmatic approach was adopted by some who felt that simulation-role-play might have a place in lessons but were also concerned by the fact that it is not the actual assessment method for A Level. Hattie (2008) did find that repeated practice led to achievement.

1.7.d.d	Erm… well I would say exam questions are more useful [than drama in preparing you for exams] because they'll sort of tell you, they'll show you what sort of questions you'll get.	5.6
1.4.c.d	The disadvantage of the drama is that I am not doing the exam questions.	5.6
2.5.a.d	Yes, I don't think it could have helped as much as it could have done because as I said before, you have to remember like how the mechanism physically looks on paper with the arrows and everything. I don't think a representation of that, like with acting, helps me to understand that but that's just my personal views.	1.4

1.1.a.d	I do think that, like drama again in certain topics is a good way to help you understand the concepts. But I do find that we can't get up and do that in the exam.…	5.4

Rapp (2007) has noted that students can often gain marks in a test through recall only, without any understanding. Some of the students in the group interviews acknowledged this, as demonstrated is in the extracts below:

2.4.g.d	You need to know the chemistry. You need to know the principles behind the chemistry. [in order to answer exam questions]	5.1
2.4.j.d	I disagree. [laughter] I think because it was nucleophilic substitution what we was doing, I think as long as you know how to do the mechanisms you will be alright	5.1
2.4.a.n	I agree with 2.4.j.d because [laughter] even if you don't understand it, if you know where to put the arrows in the right place you can get full marks for the questions. Very easy marks in an exam.	5.1

There were comments by students, typified below, who felt that organic reaction mechanisms is a topic where recall rather than understanding is appropriate. There is an acceptance by some that surface learning (Hattie and Donoghue, 2018), is enough. The comment by student 2.1.d.d seems to reinforce the work of Ellis (1994), who raises the point that one of the issues with this branch of chemistry is that there are no algorithms and each case needs to be worked out individually.

2.1.d.d	I'd say there's some things where you need more understanding and there's somethings where you need or it's easier just to learn it.	5.2
Researcher	Where does nucleophilic substitution fall in?	
2.1.d.d	I'd say it's easier just to learn it. Because the rules for it is quite confusing and there's little bits where it's not how you think it would go. So, if you just learn all the different types, you're much better off than learning how it all works. Whereas there's other stuff where I'd say it's much easier. Like when you're doing equilibrium or something, you can't just learn which way it would shift, but you need to go and understand what happens and then you can answer the questions much better. So it depends on what it's about really.	

This accords with the work of Rapp (2007). However, Cooper and Rush (2012) and Grove, Cooper and Cox (2012) have raised concerns that further progress in becoming fluent in this area of chemistry is dependent upon being able to reason at a deep level. This relies upon an ability to recognise where content has been embedded in different, often unfamiliar, contexts and also to be able to determine, from any given context, which concepts apply (Adnan, Hill and Reid, 2004). Therefore, in order to be able to work competently with a range of different reaction mechanisms there is a need for deep learning (Hattie and Donoghue, 2018).

As seen above, students differ in their approaches to answering examination questions, with one method depending on the belief that it is easier to learn by rote practice of past questions, since they believe these questions are very similar year on year. The conclusion that is arrived at by following that logic is that practicing past papers will be enough to gain the requisite marks. Although the following extracts are from Phase 3 of the study, they clearly link to the debate here and so have been included:

3.1.d.d	I think just doing exam questions over and over just helps you remember it by repetition. And when you get to the actual exam the exam question will be very similar because it will be worded slightly differently or a different chemical. And then you just know, you've done it so many times you know what to do… and you could just, redo that what you've done so many times. And then… but I thought… exam questions aren't as good for understanding.	5.3 3.3
3.5.q.d	With remembering and using exam questions I feel like a lot of exam questions across different papers are quite similar. It's very limited on what the answer can be. So, if you're doing a question on a mechanism it's very likely that it's going to be a similar type of nucleophile or something like that in the next question. So, it's easy to transfer the answer across.	5.3
3.1.c.d	All we really have to do is remember how to answer the exam questions and then you do well so….	5.2

4.9 Analysis of test script responses by factors

Test scores were analysed with respect to gender, predicted A Level Chemistry grade, number of STEM subjects taken in addition to chemistry and perceived prior classroom pedagogies.

4.9.1 Is gender a factor behind any differences between the marks for the two groups?

For both groups, test scores given in accordance to both the examination board mark scheme and the fine-grain mark scheme were analysed in relation to gender.

Examination board mark scheme

Marks awarded using the examination board mark scheme (/17) were analysed to see whether gender was a significant factor in either the drama or examination-style question groups.

Table 4.16 Descriptive statistics for marks obtained by the drama and the examination-style question group in consideration of gender when using the examination board mark scheme

Gender	Group	Mean	Standard deviation
Male	Drama	8.06	3.94
	Examination-style question	10.47	3.30
Female	Drama	9.63	3.52
	Examination-style question	9.37	3.76

A two-way ANOVA analysis was conducted to determine whether there was a statistically significant difference between the drama and examination-style question group test scores with respect to gender. The two independent variables were the teaching group (drama vs examination-style question) and gender (male vs female).

There was no statistically significant main effect of gender ($F(1, 62) = 0.07$, $p = 0.80$) nor was there a statistically significant interaction between gender and group ($F(1, 62) = 2.17$, $p = 0.12$).

There was no significant difference in test scores (as obtained using the examination board mark scheme) between the genders across the sample as a whole, nor is there an effect of gender in one group and not the other: the effect of gender was similar in both drama and examination-style question groups.

Fine-grain mark scheme

Test marks awarded using fine-grain mark scheme were analysed to see whether gender was a significant factor in either the drama or examination-style question groups.

Table 4.17 Descriptive statistics for marks obtained by the drama group and examination-style question group in consideration of gender when using the fine-grain mark scheme

Gender	Group	Mean	Standard Deviation
Male	Drama	14.81	6.77
	Examination-style question	19.13	5.36
Female	Drama	16.44	5.99
	Examination-style question	17.05	6.11

A two-way ANOVA analysis was conducted to determine whether there was a statistically significant difference between the drama and examination-style question group test scores with respect to gender. The two independent variables were the teaching group (drama vs examination-style question) and gender (male vs female).

There was no significant main effect of gender ($F(1, 62) = 0.23$, $p = 0.88$) nor was there a significant interaction between gender and group ($F(1, 62) = 1.52$, $p = 0.22$).

There was no statistically significant difference in test scores (as obtained using the fine-grain mark scheme) between the genders across the sample as a whole nor is there a statistically significant effect of gender in one group and not the other: the effect of gender was similar in both drama and examination-style question group.

4.9.2 Are there differences between test marks for the two groups when analysed in relation to predicted A Level Chemistry grades?

For both groups, test scores given in accordance to both the examination board mark scheme and the fine-grain mark scheme were analysed in relation to predicted A Level Chemistry grades.

Examination board mark scheme

In order to see whether there was any difference in the performance of students with differing predicted A Level Chemistry grades between the two groups, two categories were created based on predicted A Level grades: A*-B and C-E respectively.

Table 4.18 Descriptive statistics for marks obtained by the drama group and the examination-style question group in consideration of predicted A Level Chemistry grade when using the examination board mark scheme

Group	Predicted A Level Chemistry grade	Mean	Standard Deviation
Drama	A*-B	10.41	2.98
	C-E	7.07	3.84
Examination-style question	A*-B	10.63	3.87
	C-E	8.00	1.70

A two-way ANOVA was conducted to determine the impact on predicted A Level Chemistry grades on scores achieved when using the examination board mark scheme. The two independent variables were teaching group (drama vs examination-style question) and predicted A Level Chemistry grade.

There was a main effect of predicted A Level Chemistry grade. Students with higher predicted A Level Chemistry grades did statistically better than those with lower predicted A Level Chemistry grades: $F(1,62) = 11.51$, $p = 0.00$.

There was no interaction between predicted A level chemistry grade and group (F (1, 62) = 0.17, $p = 0.68$), the difference in performance between ‘low’ and ‘high’ performers does not statistically differ between the drama and examination question groups.

Fine-grain mark scheme

Two groups were created based on predicted A Level grades: A*-B and C-E respectively.

Table 4.19 Descriptive statistics for marks obtained by the drama and the examination-style question groups in consideration of predicted A Level Chemistry grade, when using the fine-grain mark scheme

Group	Predicted A level Chemistry grade	Mean	Standard Deviation
Drama	A*-B	17.88	5.35
	C-E	13.07	6.57
Examination-style question	A*-B	19.25	5.91
	C-E	14.90	4.38

A two-way ANOVA was conducted to determine the impact of predicted A Level Chemistry grades on scores achieved when using the fine-grain mark scheme. The two independent variables were the teaching group (drama vs examination-style question) and predicted A Level Chemistry grade.

There was a main effect of predicted A Level Chemistry grade. Students with higher predicted A Level Chemistry grades did statistically better than those with lower predicted A Level Chemistry grade: $F(1, 62) = 9.57$, $p = 0.00$.

There was no interaction between predicted A Level Chemistry grade and the group ($F(1, 62) = 0.023$, $p = 0.88$). The difference in performance between ‘low’ and ‘high’ performers does not differ to a statistically significant degree between the drama and examination-style question groups.

4.9.3 Is there a correlation between the test marks for the two groups when analysed in relation to numbers of STEM subjects being studied in addition to Chemistry?

The majority of students (*n*(drama group) = 28, *n*(examination-style question group) = 29) reported taking four subjects in the first year of their A Level studies. As in Phase 1 above, test scores for students taking either three or five subjects were not included in the study. Pearson product-moment correlation coefficients were computed for the drama and examination-style question groups for test marks obtained using both the examination board mark scheme and the fine-grain mark scheme.

Table 4.20 Pearson product-moment correlation coefficients for the relationship between the number of STEM subjects taken, in addition to chemistry, and overall test scores according to both the examination board and the fine-grain mark schemes, for both the drama and the examination-style question groups

Mark scheme	Group	*r*	*n*	*p*
Examination board	Drama	0.20	28	0.30
	Examination-style question	0.14	29	0.48
Fine-grain	Drama	0.30	28	0.38
	Examination-style question	0.18	29	0.35

For both the drama and the examination-style question group, no statistically significant correlation was found to exist between the number of STEM A Level subjects being studied in addition to chemistry and the test marks that were achieved according to either mark scheme.

4.9.4 Is there a correlation between prior classroom pedagogy and test marks?

In order to establish whether there was a correlation between prior perceived classroom experiences in chemistry and the test mark scored, questionnaire data were used to produce two composite groups: traditional pedagogy and interactive pedagogy.

Students reported how many times, in the four weeks leading up to completing the questionnaire, they had experienced specified teaching pedagogies in their chemistry lessons. These reported values were used to produce two groups: the traditional pedagogy group and the interactive pedagogy group. Composite scores for each student were then calculated using the formulae below and these values were used in the following statistical analyses.

- Traditional pedagogy score = mean of examination questions, presentations and written work values reported in the questionnaire.
- Interactive pedagogy value = mean of interactive activities such as card sorts, experimental work and group discussion values reported in the questionnaire.

The relationship between each pedagogical group and test scores for both the examination board scheme and fine-grain mark scheme was calculated using Pearson product-moment correlations, controlling for predicted A Level grades. The results of this are presented in Table 4.21.

Table 4.21 Pearson product-moment correlation coefficients, to assess the relationship between the perceived amount of prior teaching pedagogy and test scores achieved in Phase 2, according to both the examination board and the fine-grain mark schemes

Mark scheme	**Group**	**Classroom pedagogy prior to intervention**	***r***	***n***	***p***
Examination board	Drama	Traditional	0.17	32	0.36
		Interactive	0.32	32	0.07
	Examination-style question	Traditional	-0.46	34	0.80
		Interactive	-0.75	34	0.67
Fine-grain	Drama	Traditional	0.22	32	0.22
		Interactive	0.30	32	0.09
	Examination-style question	Traditional	-0.08	34	0.65
		Interactive	0.12	34	0.49

For each group (drama and examination-style question) there was no statistically significant correlation between the test scores, as obtained by either the examination board mark scheme or the fine-grain mark scheme, and the perceived prior classroom pedagogy.

4.10 Quantitative data analysis for Phase 3

This section answers the following research question: do students' marks in A Level examination questions on organic reaction mechanisms differ, in a statistically significant manner, depending upon whether or not they have been taught using simulation-role-play or practice examination questions? This question is addressed through the statistical analysis of responses to the post-intervention tests in Phase 3.

4.10.1 Context

Phase 3 involved working with the same four schools that were used in Phase 2; the teaching and learning was focused upon the reaction mechanism nucleophilic addition: the first introduction to organic reaction mechanisms in the second year of the A Level course. Following introduction to the new chemistry, the drama groups were invited to produce their own simulation-role-play, rather than using scripts prepared by the researcher, as was the case in Phases 1 and 2. Following an introduction to the new chemistry, the examination-style question groups completed and self-marked a range of examination questions, similar in format to those used in Phases 1 and 2.

4.10.2 Coding of examination question responses for Phase 3 students

All student responses to the test questions were initially coded using the original mark schemes from the examination board resulting in a maximum of 12 marks (AQA, 2018; OCR, 2018; Pearson Edexcel, 2018). As was also the case in Phases 1 and 2, some questions demanded that candidates had completed a number of steps in thinking before they could be awarded a mark. In order to establish in detail which aspect/s of a question each student had a comprehension of, a 'fine-grain' mark scheme was produced that allowed a maximum of 24 marks. To reduce the potential for researcher bias, the fine-grain mark scheme was scrutinised by a PhD chemist and an experienced A Level Chemistry teacher, both of whom were external to the study. A final diagnostic multiple-choice question was also included.

4.10.3 Inter-marker reliability

A sample of eight test scripts were selected from across the schools and marked independently by the researcher and an A Level Chemistry teacher employed in school that was not part of this study. Subsequent coding used the guidance referred to above. All coding was entered into Excel 2013 workbooks then imported into SPSS v23. An excellent degree of reliability was found to exist between the two markers for the sample of Phase 3 examination questions. The inter-class correlation for the total marks awarded was 0.92, with a

95% confidence interval from 0.63 to 0.98 ($F(8,8) = 62.84$, $p < 0.001$). For total fine-grained marks awarded the inter-class correlation was 0.98, with a 95% confidence interval from 0.90 to 1.00 ($F(8, 8) = 0.977$, $p < 0.001$).

4.10.4 Do the marks obtained by the drama and examination-style question groups differ from one another?

Sample sizes in this phase of the study are smaller than the other two phases and visual inspection of histograms led to the judgement that the data were non-parametric. The data were coded in a similar manner as they were for the two earlier phases of the study, but the nature of the data meant that the statistical analysis was less extensive than before. In order to answer this question, the test responses were analysed using total marks for each student using the examination board mark scheme and the fine-grain mark scheme. The answers to the diagnostic question were also statistically analysed for difference between the groups.

Examination board mark scheme

A Mann Whitney U test indicated there was no significant difference between the scores of students in the drama class (*Mdn* = 11.0) compared to the test scores for the students in the examination-style question class (*Mdn* = 9.50) when using the examination board mark scheme: $U = 46.00$, $p = 0.39$.

Fine-grain mark scheme

A Mann Whitney U test similarly indicated there was no significant difference between the scores of students in the drama class (*Mdn* = 22.00) compared to the test scores for the students in the examination-style question class (*Mdn* = 19.00) when using the fine-grain mark scheme: $U = 40.50$, $p = 0.22$.

Diagnostic question

The final diagnostic question yielded the distribution of answers shown in Table 4.22.

Table 4.22 Student responses to the Phase 3 diagnostic question in the drama and the examination-style question groups

Answer	Number of drama group students selecting this answer	Number of examination-style question group students selecting this answer
A	0	0
B	0	0
C	0	8
D	0	0
E	2	4
F	0	0
G	0	0
H	5	4
Spoiled paper	0	1 (answered both C and H)
Total	**7**	**17**

Although a small sample, the frequency with which the correct answer (H) was selected is greater in the drama group than the examination-style question group. A *z*-score was calculated for the population proportions: $z = 2.20$, $p = 0.03$ (proportion correct in drama group is 0.71 and in the examination-style question group is 0.24).

Although this result should be viewed with caution due to the small sample size, results for the two groups were significantly different in the direction that the drama group are statistically more likely to answer the diagnostic question correctly than the examination-style question group.

4.11 Phase 3 qualitative data analysis

Students in Phase 3 of the study were in the second year of their A Level studies (Y2) and many of their comments were coloured by the fact that they were preparing for their forthcoming external examinations. They spoke of the tension between understanding chemistry and passing examinations. In common with some of the Phase 1 and 2 students, they did not always feel the two were compatible.

4.11.1 Drama and understanding of organic reaction mechanisms

There are multiple claims made holding that the use of drama in science education significantly increases deep understanding of scientific ideas when compared to results for students taught using traditional methods (Metcalfe et al., 1984; Braund, 1999, Ødergaard 2003; Arieli, 2007). In Metcalfe's (1984) stud, surface learning outcomes are found not to differ between the groups to a statistically significant degree.

When students were asked to comment upon whether drama in the lessons with the researcher had helped promote understanding of the relevant chemistry, they spoke about the perceived differences between preparation for answering examination questions and actually understanding the chemistry. It can be seen in the comments below that students perceived simulation-role-play to be a good way to promote understanding, but not necessarily as being a good preparation for answering examination questions. The former appears to support the quantitative analysis of attitudinal data but is not supported by differences between the test scores of the two groups.

3.1.d.d	And then… but I thought…[practicing] exam questions aren't as good for understanding.	3.2

2.4.g.d	I believe that it [drama] didn't prepare me well for the exam questions but I do believe it helped me thoroughly understand the concepts and the principles behind answering the exam questions. But in terms of the exam questions directly, I don't think it was effective.	3.2
2.4.j.d	I agree. Because obviously the drama was a good way of understanding but in the exams with your arrows for instance, couldn't replicate that with the actors. So I think you had to advance on your learning.	

4.11.2 Understanding and examination questions

Phase 3 drama group interview participants were asked to discuss the relative merits of using drama(simulation-role-play) and/or practice examination questions for developing their **understanding** of the chemical concepts. There was some dissention in the resulting discussions.

One student gave voice to the idea that simulation-role-play provides a good introduction to mechanisms but that, in their opinion, it does not give the level of detail needed to answer the questions:

3.1.e.d	I think the drama helps your sort of basic understanding of sort of, chemistry like mechanisms. But if you get like I say a weird exam question, so to speak, not the standard one that says erm… give a brief outline of this mechanism, then it might sort of throw you a bit, and so the drama might not necessarily help because you've only gone through it, how it works not necessarily all sort of ins and outs of it.	5.9

Another respondent focused upon the need to understand how to answer examination questions as opposed to understanding the chemistry, and felt this could be achieved by going over examination questions:

3.1.f.d	It was good when we go through like exam questions on the board or something like that, get them explained out to you, that's probably, probably the best way to be… it will certainly help you understand how to answer the questions well.	2.7

There was agreement that practicing examination questions and using the mark scheme would assist in being able to remember what was needed to answer examination questions. Although these students are the second year of their A Level studies it is clear that, just as with students in their first year, there is a focus on 'what is needed in the examination'.

3.1.c.d	Yes, I think… erm… exam questions sort of see what you can remember about it and then if you go over them they can improve your understanding if you sort of do it enough it will help. But if you do it like, maybe once or twice and then leave it you might not fully understand it and you won't fully like remember everything about it.	5.7
3.1.d.d	I think mark schemes of exam questions can help improve your understanding because once you've done the question wrong and you look at the mark scheme and you obviously know that you don't understand it as well and then you want to do the question again until you understand it a bit more. Unless you're really lazy, but....	5.6

There was an acknowledgement that being able to get marks in an examination question does not necessarily equate to understanding the chemistry being examined.

3.1.d.d	I think that… I put a nine for remembering because… I think just doing exam questions over and over just helps you remember it by repetition. And when you get to the actual exam, the exam question will be very similar because it will be worded slightly differently or a different chemical. And then you just know, you've done it so many times you know what to do…and you could just, redo that what you've done so many times. And then… but I thought… exam questions aren't as good for understanding.	5.3 3.2
3.1.d.d	Because it's just answering questions and you do need to go through it like in a different way to help visualise or understand what's going on, so that could be why drama's better. Because you're actually moving about and visualising it. So that can help you understand it initially and then use exam questions to remember it afterwards.	5.3 3.1

One student clearly identified the tension between remembering to pass examination questions and understanding, especially when a chemistry topic is perceived to be 'difficult':

3.1.f.d	I think err… the best way to be able to remember something is to understand it and like know what happened because then you don't have to remember like the exact thing, you can just think about what's happening and then work it out from that. Having said that there's some stuff like, most of the mechanisms, it just seems like you can't really… it's just much easier to just remember exactly what happens. But in theory like the drama will probably help you better.	3.1

4.11.3 Diagnostic question

The diagnostic question had been constructed in such a way that for students to arrive at the correct answer, aside from pure guesswork, they needed to be able to break down the stages of the reaction mechanism in a step-by-step manner in order to 'mentally stop' the process at an intermediate stage. The question asked them to select the correct intermediate from a number of options. Rote learning would not help answer this question.

As can be seen in the extracts below, students identified the diagnostic question being different to A Level questions, demanding a different type of thinking.

3.5.q.d	Erm… I feel that [the diagnostic] question was quite… to me it was personally quite difficult because a lot of the erm… ones [answers to select from] we were given to identify which one was next or something like that, they were quite similar. And I felt like when I was looking at them, I wasn't… I thought it was trying to trick me, so I wasn't sure which one it was, because a lot of them were similar and I couldn't remember… where, what was next because I thought the question, to me, I wasn't really quite sure what it was asking.	4.1
3.5.i.d	It reminded me of Chemistry Olympiad questions. Erm which we did erm kind of after that, and, I don't know, it's kind of made me think that in the way it makes you think outside of the box.	4.1

As seen from the quantitative data in Section 4.10.3 above, drama students appear to have answered the diagnostic question significantly better than their peers in the examination-style question group. When questioned on the role of drama in answering this question their comments highlighted the fact that the simulation-role-play was able to help with this type of question by using step-by-step analysis, as seen in the statement below. It would appear that a high-quality mental a model had been developed; Rapp (2007) has argued that the quality of mental model reflects the depth of understanding of a concept.

3.5.h.d	I think because in the drama bit we did step by step, you could probably, if you remembered it very well you'd be able to go through it logically and think about what's next to unravel what's in the question… and reach solutions, so yes [drama helped with answering the diagnostic question]….	4.2b

4.12 Chapter summary

For all three phases of the study, when comparing the drama and examination-style question groups, there was found to be no statistically significant difference (at the 0.05% level) between the marks awarded for the answers to the examination questions in the post-intervention tests. This was the case when data from Phases 1 and 2 were interrogated for gender, predicted A Level Chemistry grade, number of STEM subjects selected for A Level in Y12, and student perception of the amount of interactive teaching and learning in chemistry lessons they had engaged in before the study.

In connection to these quantitative results, a number of themes emerged from the group interviews indicating that student responses were mixed on the question as to whether drama helped them to remember and/or understand the new chemistry. Also presented in the group interviews were ideas that were linked by an overarching concern about the need to take external examinations and the need to just pass them. These notions were often articulated in terms of the perceived need to simply practise what were taken to be predictable questions; to the extent that they would be able to remember how to gain marks.

Phase 3 included a diagnostic question designed to probe student deep level learning. Although the sample sizes were small, there was statistically significant difference between the examination-style question and drama group answers, showing that the drama group had performed better than the examination-style question group. Participants in the Phase 3 group interviews communicated that they could see how this question checked understanding and they agreed that drama (simulation-role-play) was a good way to prepare them for this type of question since it allowed step-by-step visualisation of the processes involved.

Qualitative data elicited responses revealing the use of mental modelling to draw together the macro, sub-micro and symbolic aspects of the relevant chemistry. There were discussions about the level of learning that was needed to answer examination questions, with a view expressed that rote learning by practicing examination questions was often enough to gain marks from the so-called predictable questions. For understanding as opposed to preparation for examination questions the value of drama (simulation-role-play) as a classroom pedagogy was voiced.

Chapter 5
Results and Conclusions

5.1 Overview

This chapter comprises of four main sections. The first of these presents the key findings of this study and considers them through the lens of the research questions. The subsequent sections then provide, respectively: an account of the limitations of this study; a detailing of the contributions this study has made to research; and, finally, a consideration of the implications of this project.

5.2 Key findings

This section reports the main findings of this study and interprets them with close reference to the critical literature associated with each of the research questions. In doing so, it draws ideas together in order to produce a theoretical model that both extends existing scholarship and provides a framework for explaining the results of this study.

5.2.1 Do students' marks in A Level examination questions on organic reaction mechanisms differ, in a statistically significant manner, depending upon whether they have been taught using simulation-role-play or practice examination-style questions?

No statistically significant differences between the marks obtained by drama and examination-style question groups were identified, whether analysed with respect to gender, perceived prior learning experiences in chemistry classes, number of STEM subjects studied or predicted A Level Chemistry grades. This applied to responses to past examination questions marked using both the examination board mark schemes and fine-grain mark schemes and the eight marks selected for individual analysis. This finding held when the drama group used a pre-prepared script or wrote and enacted their own simulation-role-play.

It appears that the two different pedagogical approaches have made no statistically significant difference to the ability of students to complete the post-intervention assessment items (examination questions); this is despite the qualitative data analysis indicating that students felt that practicing examination-style questions prepared them better for answering examination questions than the use of simulation-role-play. When thinking about answering formal A Level questions, a theme that emerged in the group interviews was students claiming that it was not always necessary to understand the relevant chemistry, and that continued practice of past papers was all that was needed to pass the external examinations. These results pertain to the issues referred to by Rapp (2007), namely that examination questions can often be answered by the recollection and recognition of repeated practice examination questions. This view corresponds with the work of Ferguson and Bodner (2008) who found that, for many students of A Level age, there is little or no meaning attached to the arrows in reaction mechanisms and that there is a heavy reliance on memorisation of individual mechanisms. If, as students claimed in this study, there is enough commonality between examination questions year on year, it is no surprise that some students adopt an approach based upon simply learning rather than understanding.

In order to investigate this claim further, one useful source of material is the current Ofqual GCE subject guidance for the sciences, which stipulates the following distribution of assessment objectives (Ofqual, 2017, Section 2.35).

Table 5.1 GCE A and AS Level subject level assessment objectives for Science (Ofqual, 2017, Section 2.35)

Assessment objective	**Description**	**% of A Level total mark**
AO1	*Demonstrate knowledge and understanding of scientific ideas, processes,* techniques and procedures	30-35%
AO2	*Apply knowledge and understanding of scientific ideas, processes,* techniques and procedures: • *in a theoretical context* • in a practical context • when handling qualitative data • when handling quantitative data	40-45%
AO3	*Analyse, interpret and evaluate scientific information*, ideas and evidence, including in relation to issues, to: • *make judgements and reach conclusions* • develop and refine practical design and procedures	25-30%

The italicised sections of text in Table 5.1 represent the statements in the assessment objectives that are most relevant to organic reaction mechanisms, demonstrating that questions could be set at different levels, classified by Ofqual as the assessment objectives AO1, AO2 and AO3. The three assessment objectives have parallels with the categories of learning suggested by Hattie and Donoghue (2018): surface learning (AO1), “factual and content” (Hattie and Donoghue, 2018, p.98); deep learning (AO3), “integrated and relational” (Hattie and Donoghue, 2018, p.98); and, lastly, the transfer stage of learning identified as application of learning to new situations (AO2). With the legally enforced Ofqual weightings of AO1 and AO2, it is possible that up to 75% of the available marks could be gained via these two assessment objectives, supporting the thoughts reported by students that they considered they could pass their A Level examination without the need to apply higher level thinking skills such as analysis, interpretation and evaluation. It is unlikely that in any given A Level Chemistry paper that 75% of the marks would preclude the use of understanding, but is indicative that many of the marks awarded will rely upon recall.

In contrast to the results above, the diagnostic question in Phase 3 of the study demonstrated a statistically significant difference between the drama and examination-style question groups. In that phase, the drama group wrote and enacted their own script. The difference showed the drama group significantly outperformed the examination-style question group. This result endorses the view that students writing and subsequently enacting simulation-role-play scripts, in the context of this study, has led to their possessing a demonstrably deeper level of thinking of the content when compared to students in the examination-style question group. Both Swick (1999) and Bateson (1994) have written in support of the idea that students writing and performing a script leads to a sense of ownership and higher levels of engagement; Bateson has postulated that this will result in enhanced learning. This dovetails with the use of group work to promote learning, albeit with the caveat that the particular nature of the group work is critical in terms of supporting this learning. Student comments in the group interviews did indicate that group dynamics are influential in determining the quality of learning outcomes, with relationships within the group being critical.

Stricklanda, Kraft and Bhattacharyya (2010) have argued that, in order to be able to interpret organic reaction mechanisms successfully, complete mental models need to have been established. Similarly, Rapp (2007) endorses the notion that without robust mental models students cannot competently tackle questions in new contexts, or think critically about materials presented.

The diagnostic question used in Phase 3 of this study, it was agreed by two academics in the field of chemistry education, asked students to think at a deep level. In this diagnostic question, students were asked to first imagine that a reaction had been stopped part way through and then to determine the intermediate in that reaction. In order to answer correctly, other than by chance, a robust mental model would need to have been established.

Answer E, which represented the final product of the reaction rather than the intermediate was chosen as correct by 24% of the examination-style question group, and by 29% of the drama group, in agreement with the assertions of Bhattacharyya and Bodner (2005) that some students place no meaning upon the arrows in a reaction mechanism and look instead for the final product of a reaction, irrespective of the mechanistic consequences.

Responses from the drama group were split between two answers, H and E, whilst those for the examination-style question group were distributed between H, E and C, including a 47% response rate to answer C. The implication is that these latter students have appreciated there is movement of some sort, they do not fully appreciate that this involves the movement of charge. There is partial understanding of the process, therefore an incomplete mental model has been formed, dovetailing with the ideas of Rapp (2007) who proposes that incomplete mental models lead to an inability to competently tackle questions in new contexts.

Responses between the two groups for the ‘correct’ answer, H, varied between the groups with a 71% selection rate for the drama group, and a 24% selection rate for the examination-style question group. This indicates a higher proportion of students in the drama group have produced robust mental models when compared to the examination-style question group. This accords with Stricklanda, Kraft and Bhattacharyya (2010) who argue that complete mental models are a necessary component of being able to successfully understand organic reaction mechanisms.

The findings that resulted from the first research question reinforce those in the wider literature and suggestions such as those made by both Ødegaard (2003) and Metcalfe et al. (1984) that factual recall through the use of drama in science education is not necessarily improved above that of the control group. Equally, the findings also support the arguments advanced by Metcalfe et al (1984), Braund (1999) and Arieli (2007) that posit deeper understanding of scientific ideas is significantly increased following drama intervention when held in comparison to the control group.

5.2.2 How do students perceive the use of simulation-role-play in their recall of organic reaction mechanisms?

Analysis of the Likert question for Phase 1 demonstrated a statistically significant difference, with the examination-style question group reporting that the chemistry was easier to remember when compared to the responses from the drama group. In Phase 2 of the study, there was no statistically significant difference between the responses of the two groups for the same Likert scale. Despite this, for both phases there was no statistically significant difference between the scores of the two groups obtained in the post-intervention assessment items. In order to try to attempt an explanation of these differences it is useful to look at any lesson modifications between Phase 1 and Phase 2 of the study. As described in Chapter 3 of this thesis, it became apparent in the lessons for both groups, during Phase 1, that there was too much content and that the lessons were rushed, especially with larger class sizes; consequently, the amount of content was reduced for Phase 2 of the study. A second modification was the addition of a common examination question into the lesson for both groups in the final ten minutes of each lesson. It is possible that the reduction in content helped students feel less pressurised, although no students articulated this in the group interviews. This is not surprising as the groups were different cohorts, so no students experienced both Phase 1 and Phase 2 of the study.

When considering what students could recall from the lessons, there were instances of individuals being able to remember the use of humour in the classroom, but how it related to the chemistry was unclear to them. Although the utilisation of humour was commonly identified as having been a fun element, some students, however, felt that it was childish and had no place in the lessons. Whilst humour was cited as something that was remembered from the lessons, there were no examples to be found in the group interviews that indicate whether, or how, this helped with recall of chemistry. In the scholarly literature that currently exists on the subject, there is a full spectrum of claims concerning the impact of humour upon learning: Wanzer and Frymier (1999) argue it to be positive; Bolkan, Griffin and Goodboy (2018), conversely, hold its effect to be negative; and Houser et al. (2007) posit instead that it has no significant impact at all. This study would appear to support the last of those positions: that humour has had no impact on learning of the relevant chemistry.

On the other hand, body movement and the use of props in the classroom seemed to assist some students in being able to recall the new chemistry. They were clearly able to use the macro aspects of the simulation-role-play, e.g. moving pompoms and ruler, and to articulate what these represented along with their roles in a reaction mechanism. There were also examples of instances in which students could link macro and sub-micro aspects in a sophisticated way, e.g. being able to recognise that in different stages of a reaction the felt balls represented electrons in different contexts, such as lone pairs of electrons or electrons in a covalent bond. For students to function as successful scientists it is necessary for them to be able to move freely between the macro and sub-micro aspects of a reaction (Kolari and Savander-Ranne, 2004). For some students it appeared that having a physical three-dimensional representation (macro) helped them to see which electrons were moving and where they were moving to and from (sub-micro). This relationship between macro and sub-micro aspects helps to develop a suitable mental model to draw upon in the future, and therefore lays a foundation for recall of the relevant chemistry. Some students referred to body movement as being useful in the recollection of the relevant chemistry, with the direction and movement of arrows identified as being one aspect that helped with recall. For those students it appears that a successful response to the challenge of making ontological shifts as discussed by Chi (2005) is facilitated by the use of simulation-role-play. As identified by Bhattacharyya and Bodner (2005), the part that the curly arrows play in a mechanism seems to be understood to a lesser extent by many students. It may be that the use of simulation-role-play assists with recall of the movement of electrons, as represented by curly arrows, but does not necessarily support understanding of the underlying processes. This referral of students to body movement in the simulation-role-play sequences seems to support the work of Wohlschläger and Wohlschläger (1998) who inferred that physical movements (in this study, simulation-role-play), and mental models of movement are linked.

This was not, however, the case for all of the students. There were concerns raised about being nervous when performing in front of the class, and so being limited in their ability to engage with the chemistry content. Some students found that taking part in the simulation-role-play led them to focus solely on their own part in the drama and so prevented them from being able to recall the complete reaction. Although the students did not discuss the idea of their role as observers very often when they did, they tended to share the same view that they found watching the simulation-role-play useful. This is in line with the findings of Braund (1999) and Peleg and Baram-Tsabari (2011). One student raised the concern that they could not be sure they could depend on the accuracy of what was being presented by the other students and there were other examples of students feeling confused and wanting to just go through the chemistry with note taking and written exemplar materials.

5.2.3 How do students perceive the use of simulation-role-play in their understanding of organic reaction mechanisms?

For Phase 1 of the study, statistical analysis of the relevant Likert scale responses revealed a statistically significant difference between the responses provided by students from the drama group and the examination-style question group. Students in the examination-style question group perceived the classroom pedagogy that they had experienced to have helped them to understand the chemistry to a greater extent than did their peers in the drama group. These perceptions were not borne out by the scores obtained for the post-intervention assessment items. There were no statistically significant differences between the test scores of the two groups in Phase 1 of the study.

For Phase 2 of the study, the results were different, with the statistical analysis of the relevant Likert scale revealing no statistically significant difference between the two groups' perceptions of how well they felt the pedagogy they had experienced assisted in their understanding of the relevant chemistry. Phase 2 also revealed no statistically significant differences between the scores from the post-intervention assessment items. The topic covered was the same in both phases but in order to better account for the differences between the Likert question responses it might be worthwhile to reconsider the differences between the ways in which the lessons were presented in the two phases. This has been described in detail in Section 3.4.3 and summarised, along with possible explanations in Section 5.2.2.

Phase 3 revealed no statistically significant differences between the scores from the post-intervention assessment items based on past examination questions. Accordingly, the conclusion to be drawn here is that both pedagogies have equipped students equally well to answer examination questions. However, in Phase 3 there was a statistically significant difference between the answers of the examination-style question group and drama group to the diagnostic question. In their responses to the question, the drama group outperformed the examination-style question group to a statistically significant degree, and the aim of the diagnostic question was to assess deep learning (Hattie and Donoghue, 2018). These results support claims made by those such as Metcalfe (1984), Arieli (2007) and Braund (1999) who point to the use of drama in science education as a means by which to promote deep learning. Considering the evidence, it would appear that the use of embodied learning in the form of simulation-role-play in this study led to an increased appreciation of the differing ontological formats of macro, sub-micro and symbolic representations used in the field of science. This is supported by comments from students in the group interviews who stated that they found the links between two-dimensional (symbolic) and three-dimensional (macro) representations to have helped them to see both which electrons were moving and where they were moving to and from. Some students reported they were able to move between the different representations when they thought about the lesson that utilised simulation-role-play. This fluency in working with the different representations can lead to the development of strong mental models, a prerequisite for being able to produce and interpret organic reaction mechanisms (Stricklanda, Kraft and Bhattacharyya, 2010).

In this study, a diagnostic question was utilised in Phase 3 but not in Phases 1 and 2. In Phases 1 and 2, the drama group performed using a script and props provided by the researcher whereas in Phase 3 the drama group wrote their own scripts and selected their own props from a range provided by the researcher. This means that it is not possible to say whether the enhanced performance in Phase 3 was solely due to the use of simulation-role-play or whether the process of engaging with the development of their own script was also an important factor. Responses from the group interviews included those reporting that writing scripts gave a sense of ownership and therefore led to a perception of greater understanding of the chemistry. This links to the work of Chi (2005) who describes emergent processes arising as a result of initial direct processes.

Comments from students in the interviews support this, with there being a number of statements pertaining to the care taken in selecting the necessary props, e.g. a gold star to represent a chiral carbon. This chimes with the work of Swick (1999) who advocates the use of script writing to increase a sense of ownership and engagement with the relevant content. Bateson (1994) argued that increased ownership and engagement leads to enhanced levels of learning. There were also comments regarding students having no ownership of the pre-prepared scripts and this leading to a lack of engagement.

Not all students were happy with writing their own scripts, and there were also comments about some silliness occurring in lessons when they were presented with all the props. Teachers commented they felt there were too many different props available for the students and if they were to run this lesson themselves they would limit the range of props. The researcher observed one group selecting props with an evident desire to devise a simulation-role-play that would give them the opportunity to use party poppers, and that became the driving force behind the script as opposed to the chemistry itself. However, the researcher also observed another group write out the mechanism underpinning the simulation-role-play which was subsequently used to select props to represent that mechanism.

In instances when students felt they did not like writing their own scripts this was often related to insecurities about their ability to write a script to represent the correct chemistry; in such cases, those students reported they would rather rely on notes from the teacher.

5.2.4 How do students perceive the use of simulation-role-play in preparing them for answering examination questions relating to organic reaction mechanisms?

In both Phase 1 and Phase 2 of the study, there was a statistically significant difference between the two groups of students' perceptions of the helpfulness of the lesson they experienced for helping prepare them for answering examination questions; this is in contrast to the post-intervention assessment scores that evidenced no statistically significant difference between the groups in either phase of the study. The examination-style question group perceived the pedagogy that they experienced to be more effective in terms of preparing them to answer examination questions than did the drama group. There were many comments relating to the fact that A Level grades are awarded in response to performance in written examinations and therefore they felt that the more practice they had in this type of work the better they would get at answering these questions. This is in agreement with the findings of research undertaken by Hattie (2008) which ranked repeated exam practice above the use of drama for the achievement of stated learning outcomes. Students in the group interviews spoke of practice examination questions allowing them to develop exam technique. Whilst acknowledging that this is not the same as understanding the chemistry, they agreed that developing exam technique is as important, if not more important, than actually understanding the relevant chemistry.

Responses from students in the group interviews indicated a range of different perceptions about the effectiveness of simulation-role-play in preparing them to answer examination questions. A minority of students spoke of how they were able to recall the simulation-role-play when answering the post-intervention assessment items (examination questions) and to use these mental images to answer the questions. One student was able to use mental models generated from the drama experiences and then, as they answered more questions, they visualised the reaction rather than the simulation-role-play in the lesson. This example exemplifies what Taber (2013) described as using scaffolding to promote ideal learning.

It seems a tension exists between the wish to gain the desired A Level grade and to understand the relevant chemistry. Some students articulated the need to gain a desired grade and were not concerned with understanding the content. Some were aware of this tension but felt that it was not necessarily unacceptable, unless they were going on to study chemistry beyond A Level, to not fully understand the work.

As one student said:

> Even if you don’t understand it, if you know where to put the arrows in the right place you can get full marks for the questions. Very easy marks in an exam. (2.4.a.n, 2016).

Students were preoccupied with repeatedly practicing past examination questions as a means for gaining their desired grade in the final external examinations. Some students commented that they believed the questions to be similar to each other across the years and so, therefore, by working through past examinations they were likely to come across questions in their final A Level examinations that they would find familiar and therefore be able to answer correctly.

That thinking echoes some of the concerns raised by Lin (1982) and Nutt (2017), the latter stating that “If you make data generation [grades] the goal of education then data is what you will get. Not quality teaching.” These concerns were also expressed by McGregor (2012), who pointed out that KS2 teaching had been influenced by the “high stakes testing agenda” (p.1145).

With large numbers of young people entering higher education, it becomes clear why they are concerned about the A Level chemistry grade they are awarded. In the 2016/7 academic year, 20,985 fulltime first year undergraduates enrolled in physical science degrees in the United Kingdom (Higher Education Student Statistics, 2018) with a further 9,850 students enrolling to study medicine or dentistry (Higher Education Student Statistics, 2018). UCAS (2018) advise that over 20,000 applications annually are received for the 6,000 places in UK medical schools. With medical schools requiring at least three A grades at A Level, usually including chemistry (Premed, 2018), students will be concerned about achieving the grades needed for admission to their desired courses. When taking into account how high stake the A Level Chemistry grade award is, potentially determining the future career pathway for many students, it becomes apparent why understanding might be sacrificed at the altar of grades.

5.2.5 A theoretical model to explain the results

As reviewed in chapter 2 the literature links the ability to function as a proficient chemist with the capacity to fluently manipulate the different aspects of Johnstone's triangle; navigating between the three levels of macro, sub-micro and symbolic in order to construct meaning of a scientific concept (Johnstone, 1991). In particular Grove, Cooper and Rush, 2012, identified this skill set as necessary for the understanding of organic reaction mechanisms.

The need for understanding (deep learning) as opposed to surface learning is reinforced by the fact that there are no algorithms for working in this area of chemistry; each mechanism is unique, needing to be worked through step by step (Ellis, 1994). The need for a strong mental model is key to being able to interpret and predict more complex mechanisms (Stricklanda, Kraft and Bhattacharyya, 2010).

The following sections first argue why the use of simulation-role-play is a pedagogy well suited to developing aspects of Johnstone's (1991) triangle, comparing this with the experiences of the practice examination-style question group. Secondly the case is made for the development of stronger mental models by students in the drama group when compared to students in the examination-style question group. This leads to a proposed explanation of why there were no statistically significant differences between the two groups for the assessment items using past A level examination questions, while the drama group outperformed the examination-style question group, to a statistically significant degree, on the diagnostic question.

Simulation-role-play and Johnstone's triangle

Macro experiences designed to stimulate macroscopic conceptualisations of reaction mechanisms in students are few and far between, with much laboratory practical work relating to this topic unsuitable for the equipment available in a typical 6th form chemistry laboratory. As an alternative to practical work the embodied experiences resulting from simulation-role-play in the drama groups provide the opportunity for the construction of macro level conceptions of the chemistry being represented.

Dorion (2009) notes that drama is a pedagogical approach effective in encouraging learning for concepts relying on complex analogies with Jaques (2000) noting that activities such as role-play-simulations allow students to manipulate representations of scale. Both of these are crucial in being able to make sense of the invisible, sub-micro aspects of reaction mechanisms.

Having established that simulation-role-play can assist in the construction of macro conceptualisations there follows a theoretical model to account for how simulation-role-play may support the development of sub-micro conceptualisations. The sub-micro is a world not visible to the student, and yet, in order to make sense of organic reaction mechanisms they will need some personal understanding, including an appreciation of 3D shapes of molecules and ions, their interactions with each other, the movement of electrons and fluidity of charge as reactions progress. Use of simulation-role-play invites the student to exploit the ability to step out of the ‘real world’ into alternative worlds of their own construction. This transformation of worlds, Rasmussen (2010) claims is realised by the ability of drama to transform a learner’s experiences through the recognition of new shapes and forms. Courtney (1989) uses the term “as if”, describing “the transformation of being into something else; turning the actual into the fictional in order to work with it” (p.14), a concept referred to by Pemberton-Billing and Clegg (1965) as “mental mobility” (p.23).

These acts of transformation are brought about via a relationship that exists between the imagined and the real worlds that Boal and McBride (1979) refer to as “metaxis” (p.74); the interface between the participant and their fictitious world. The actor is able to make sense of the world at both levels simultaneously and can therefore create alternative understandings or ideas within which the drama is situated (Boal and McBride, 1975).

The ‘real world’ experiences of the simulation-role-play enable students to access the chemistry in a concrete embodied way and to construct what Taber (2013) refers to as macroscopic conceptualisations at a descriptive level. The invisible sub-micro world can be accessed through the use of embodied learning; the macro experiences providing a conduit to “metaxis” (Boal and McBride,1979, p.74) allowing students to create their own transformations in the sub-micro world with its associated understandings. An embedded aspect of the simulation-role-play was the use of appropriate technical language and the writing of the reaction mechanisms, introducing clear links between the three levels of Johnstone’s (1991) triangle. Furthermore, during the initial section of the lesson when the new chemistry was being introduced the researcher was demonstrating the use of the drama kit and, as the demonstrated simulation-role-play progressed, the associated symbolic representations were written on the board. The emergent relationships between the three aspects of Johnstone’s (1991) triangle in the drama lesson are represented in Figure 5.1.

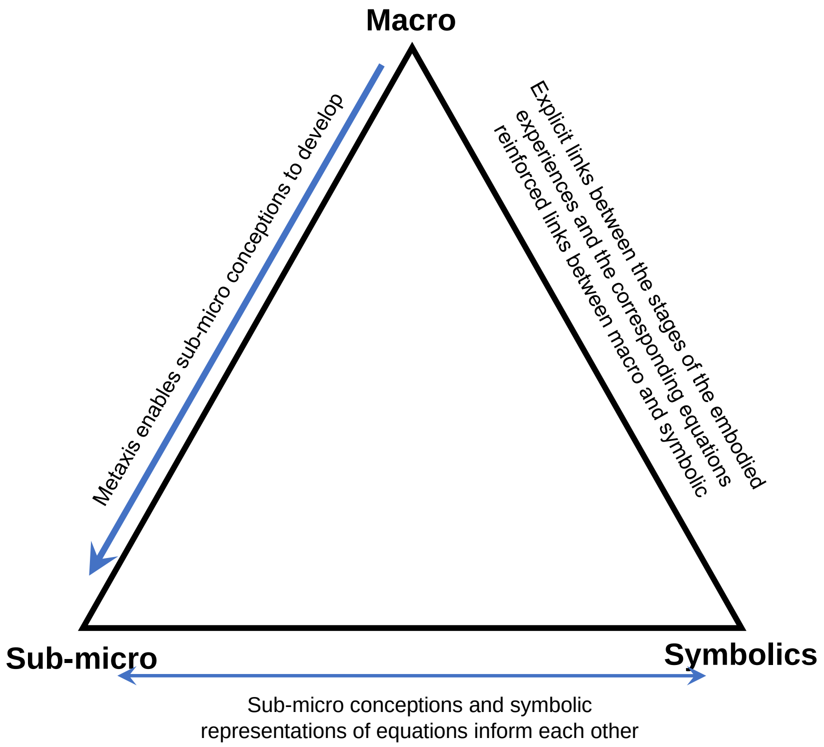


Figure 5.1 The relationship between the macro, sub-micro and symbolic levels in the drama lessons.

In the case of the examination-style question group there were no embodied macro experiences. Using the logic from the preceding paragraphs it can be postulated that the macro dimension of conceptualisation was less strong in these lessons and there were no explicit opportunities for “metaxis” (Boal and McBride,1979, p.74) to occur, minimising any meeting of macro and sub-micro worlds, resulting in less robust understandings at the sub-micro level when compared to the drama group. The initial teacher led presentation in the examination-style lessons was accompanied by question and answer and focused on talk about the sub-micro aspects of the chemistry with the accompanying symbolic equations being presented. These same levels of Johnstone’s (1991) triangle were then mirrored in the subsequent student activities as they completed and marked practice examination-style questions.

The links between developing aspects of Johnstone's triangle and the construction of mental models

In this study, the students' mental models find expression in the form of written responses to a range of assessment items including examination questions and a diagnostic question. For students to produce these responses, they need to successfully engage with symbolic two-dimensional representations of reactions presented in the form of examination questions, link those to the sub-micro world of what is occurring at a particulate level, including three-dimensional awareness of molecular structure, and then retranslate these ideas into two-dimensional written answers. As discussed above, many students do not have this skill set and rely merely upon rote learning or recall (Ferguson and Bodner, 2005). However, in order to answer the Phase 3 diagnostic question successfully, students need to have formed an appreciation of the three-dimensional geometry of the reactants and use this to determine how the reaction would proceed to an intermediate. This intermediate structure then needs to be mentally transformed into a two-dimensional format in order to identify the correct representation from those presented. In order to carry out this set of processes, a student needs to have the ability to fluently navigate between the sub-micro and symbolic representations of chemistry as exemplified by Johnstone 1991, 2010; Grove, Cooper and Rush, 2012. Further to that, students must also meet the accompanying challenge of mentally converting two-dimensional representations of molecules to three-dimensional ones, and *vice versa*, that Ellis (1994) identified as being a barrier to the successful construction of reaction mechanisms. These processes have a high level of demand and depend upon strong sub-micro conceptualisations.

During the intervention lessons students in the drama groups worked with macro, sub-micro and symbolic interpretations of the reactions, whilst those in the examination-style question group worked with sub-micro and symbolic representations. Based on the statistical findings in Chapter 4, it would appear that both pedagogies are appropriate for teaching and learning to facilitate answering A level examination questions on this topic.

It appears that there must have been a difference between the quality of learning produced through the use of simulation-role-play, as opposed to the completion and marking of practice examination-style questions. This assumption is based upon the fact that the drama group outperformed the examination-style question group in the Phase 3 diagnostic question in a statistically significant way ($p = 0.03$).

Figure 5.2 shows the links between the aspects of Johnstone's (1991) triangle accessed in both types of lesson (drama and examination - style) and their links to the minimum requirements needed to answer both the examination questions and the diagnostic question.

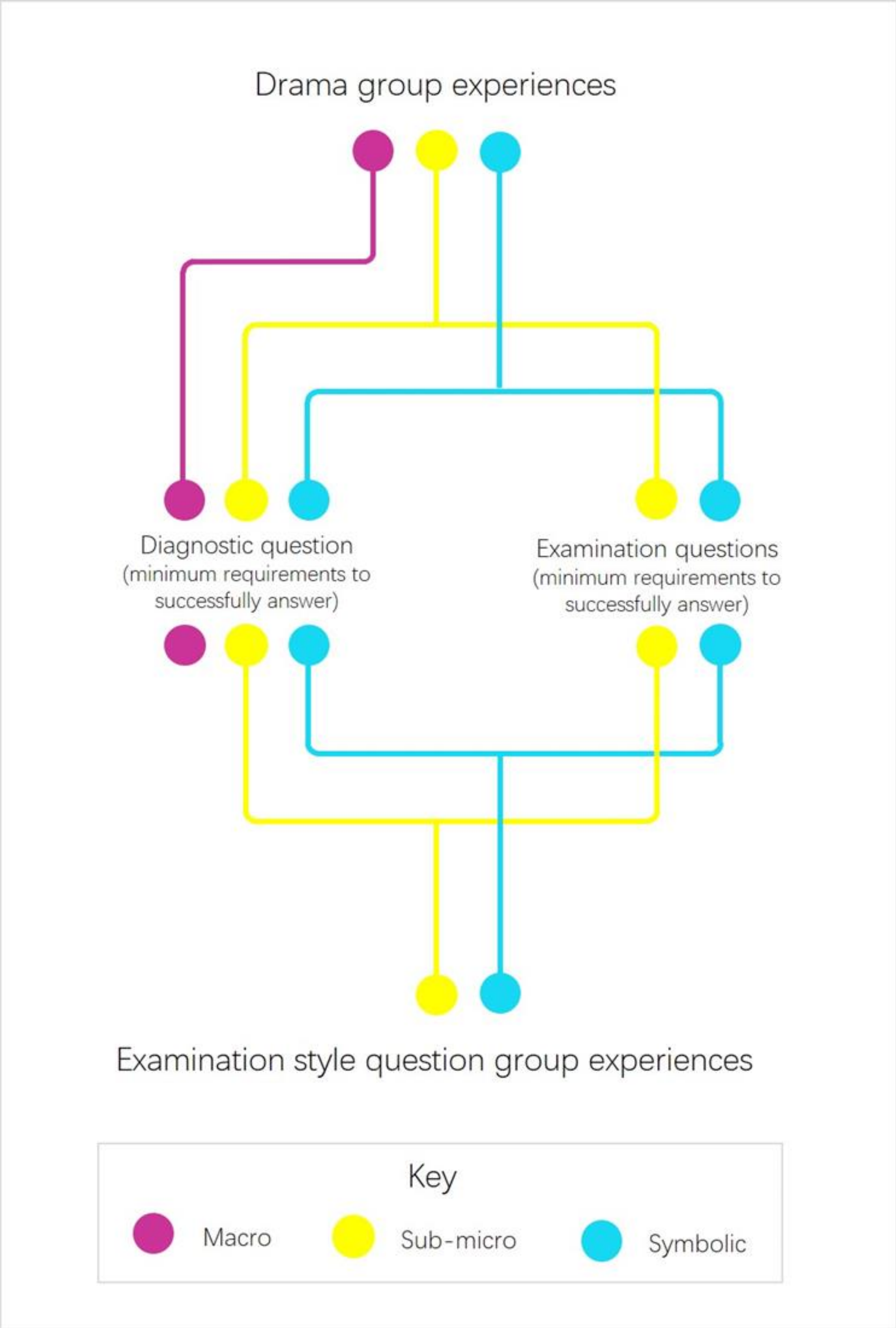
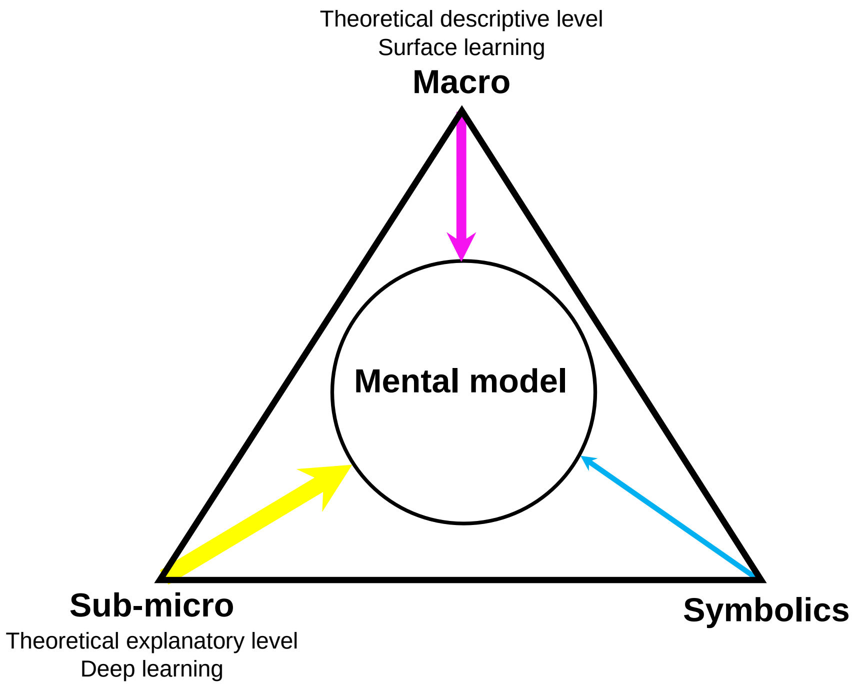
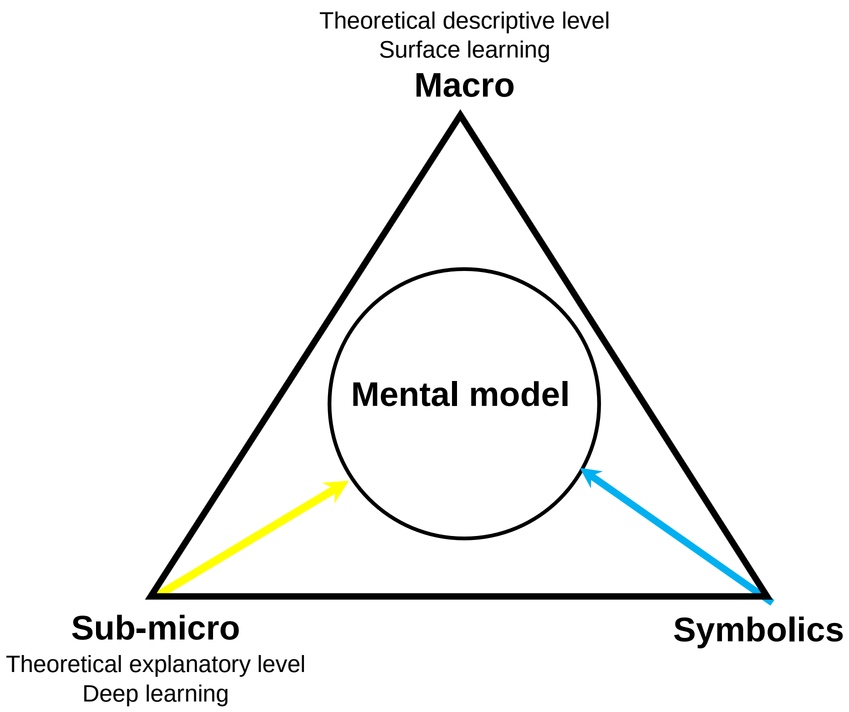


Figure 5.2 The macro, sub-micro and symbolic aspects of the intervention lessons and the minimum requirement needed to successfully answer the different types of assessment items

Each of the three dimensions of learning will contribute to the mental model a student produces and the resultant mental model will determine how well a student is able to answer any of the assessment items, including the diagnostic question. The varying contributions of the aspects of the three levels of Johnstone's (1991) triangle for the two groups (drama and examination-style question groups are shown in Figure 5.3. The thickness of the arrows is indicative of relative contributions, though in no way are these quantitative representations. The colour key is the same as for Figure 5.2.



a. Drama group



b. Examination-style question group

Figure 5.3 Differing contributions of the three levels of Johnstone's (1991) triangle to the construction of mental models for a. drama group and b. examination-style question group

This thesis proposes that the embodied learning experience of simulation-role-play contributed to the construction of strong mental models: the embodied aspect of the lessons contributing to a conceptualisation of the macro dimension that was absent in the examination-style question group. As mental models have spatial, physical and kinaesthetic dimensions (Hostetter and Alibalia, 2008), it is proposed here that embodied learning, also possessing those dimensions, contributed to the production of strong mental models by the drama students through the development of the descriptive level conceptualisation of the reaction mechanisms to a greater extent than the practising and marking of examination-style questions. Additionally, as proposed above, the merging of real and imagined worlds through the use of simulation-role-play contributed to the development of stronger sub-micro explanatory level conceptualisation of the reaction mechanisms than the practicing and marking of examination-style questions.

Taber (2013) differentiates the type of learning attributable to macro and sub-micro levels of Johnstone's (1991) triangle, stating that the macro contributes at a theoretical descriptive level of learning while the sub-micro provides a theoretical explanatory level of learning. When referring back to learning theory discussed in the literature review (Section 2.6.2) it becomes clear that the macro descriptive level of learning can be described as surface learning and the sub-micro explanatory level of learning is an aspect of deep learning. The ideas above would indicate that as students move from a concrete macro learning, adding a more abstract sub-micro understanding of the relevant chemical concepts they are transitioning from shallow to deep learning. Paraphrasing Kegan, students are moving from working *within* the frame to *reconstructing* the frame (p.36) with new sub-micro frameworks to draw on. These transitions have occurred through the use of scaffolding, as promoted by Taber (2013). In this case the scaffolding to trigger transition to deeper levels of learning has been engagement in simulation-role-play. Interpreting through the lens of Tregaust (2003) it can be said that the use of simulation-role-play has promoted the development of relational, deep, understanding via mental integration of the three aspects of Johnstone's (1991) triangle, when applied in the context of organic reaction mechanisms.

These processes resulted in a larger proportion of students in the drama group developing robust mental models than did those in the examination-style question group. This appears to have equipped the drama students to answer better the diagnostic question, in a statistically significant way, than their peers in the examination-style question group. Whether the same thing applies when simulation-role-play is used with a prepared script as opposed to the utilisation of simulation-role-play coupled with the students writing their own script is not something that can be verified by this study.

As there were no statistically significant differences between answers to the examination questions in all three phases of the study, it would appear that the mental models developed by students in both of the groups were enough for the level of demand needed to answer these questions.

5.3 Limitations of the study

This section discusses the limitations of the study. None of these limitations compromise the reliability or validity of the results obtained.

5.3.1 Sampling

In 2019 there were 3,448 secondary schools and 2,319 independent schools (Department for Education, 2019, p.4), 381 further education colleges and 94 sixth form colleges (British Education Suppliers Association, 2019). This study cannot claim to provide representation for all of these as it worked with a subset of schools and colleges, selected for the study on an opportunistic basis. The schools used in the study were all within a two-hour driving distance from the researcher's work base. Initially Phase 1 of the study included a combination of state 11-18 schools, independent schools and a further education college. Because of the reasons discussed in Chapter 3, Phases 2 and 3 of the study worked solely with state 11-18 schools.

A second limitation relating to sampling was the allocation of students to the drama or examination-style question groups. This was carried out by random allocation of whole teaching groups, i.e. this was not true random sampling. It could be argued that this reflects the way in which teaching is carried out in the real world, and that therefore validity was not compromised.

5.3.2 Researcher bias

In an attempt to minimise the number of variables, all intervention lessons (drama and examination-style question lessons) were taught by one researcher. Although the lessons were designed to deliver the same material using different pedagogies, it is not possible to control for any subconscious researcher bias for or against either of the teaching pedagogies that might exist. For group interviews, the statements were pre-printed on cards as stimulus material to promote discussion. In Phase 3, students in the group interviews ranked their agreement with statements on a scale of 1-10 and declared them before starting to speak. This ensured that students had made choices without any input from the researcher. These statements had come directly from answers given in the questionnaire responses. One host teacher, who had sat at the back of the class while a group interview had taken place, commented that the researcher had been much more balanced in the group interviews than they had expected. The teacher in question had anticipated a distinct bias in favour of the use of drama but they had not observed this.

5.3.3 Diagnostic question

A diagnostic question probing deep understanding was used only in Phase 3 of the study. Because of this, it was not possible to determine whether the enhancement of deep learning took place due to the use of teacher led simulation-role-play with scripts written by the researcher, solely to the student led writing and enactment of their own scripts, or to both of these as a contributory factor to the embodied learning that took place.

5.4 Contribution to the field

This study has contributed to the existing research in the field by focusing on areas that have been previously under-represented. Firstly, research into the use of drama in science education has typically taken place working with students aged 6-14 and, in contrast to that, this study focused on students aged 16-18. Secondly, much work has had its focus on the role of drama in the “working scientifically” aspect of the science curriculum as opposed to scientific concepts. A smaller number of studies have focused on scientific concepts, often gathering qualitative data to support findings. This study selected aspects of organic chemistry in preparation for A Level written examinations for the content and, in contrast to many other studies, set up a quasi-experimental design, enabling extensive statistical analysis to be carried out.

The results of this study add to the body of literature that seems to indicate that drama, in the form of simulation-role-play can be successfully utilised as a pedagogical tool in the classroom to teach aspects of chemistry. It adds to the existing literature that claims that drama can be used in order to help promote the deep learning of certain scientific concepts. This study can make no claims that the use of simulation-role-play in science education is any more or less effective than the use of examination-style questions in preparing students to answer A Level questions on organic reaction mechanisms. It does however point to the use of simulation-role-play as an effective classroom tool to enhance deep understanding in this area of chemistry, a necessary prerequisite to succeed in the study of organic chemistry at undergraduate level and beyond. The phase of the study where this result was manifest was where the drama group had written and performed their own script, following an exposition of the new chemistry.

Unlike other literature, this study explores theories as to why the use of drama appears to enhance deep learning. The use of strong mental modelling has been established as a necessary prerequisite to being a successful organic chemist; a link has been hypothesised between the role of embodied learning, with simulation-role-play as an example of such, and the construction of strong mental models. This link is supported by work in the field of neuroscience. This thesis has proposed that the use of embodied learning supports the development of strong mental models using the macro, sub-micro and symbolic representations, as opposed to just sub-micro and symbolic representations used in carrying out practice examination questions. It is proposed that the spatial, physical and kinaesthetic aspects of the embodied simulation-role-play contribute to establishing the macro dimension of scientific representation to the emerging mental model. The invisible sub-micro world can be accessed through the use of embodied learning with macro experiences providing a conduit to metaxis; allowing students to create their own transformations into the sub-micro world with its associated understandings. This facilitates movement from macroscopic, descriptive conceptualisations to deeper sub-micro, explanatory level conceptualisations. As summarised by one student from the drama group, “as opposed to just writing it out and thinking ‘this goes there’ [**what**] you can kind of see **why** it went there.” (1.7.b.d, 2015). This model gives a theoretical insight into how simulation-role-play functions in the “drama space” (Braund, 2015, p.110) to close the gap between the “learner’s world of knowing” and the “science world of knowing” as discussed by Braund (2015, p.110).

5.5 Recommendations and implications

The findings of this study seem to indicate that it may be of value to repeat the project with this age group but to incorporate different areas of the A Level Chemistry specifications or other science specifications. During group interviews, students suggested that drama might lend itself to many other chemistry concepts, such as dynamic equilibrium. They indicated that they thought drama would not be appropriate for the teaching and learning of chemistry concepts with a mathematical content, e.g. thermodynamics. As this is considered a difficult topic for students (Le Maréchal and El Bilani, 2008), it may be a fruitful area for future research, especially bearing in mind the work on embodied learning in the field of mathematics education (Nemirovsky and Ferarra, 2009).

Not all students found simulation-role-play a useful pedagogy for remembering or understanding aspects of the chemistry relevant to this study, citing scripts as being an obstacle in terms of clarity of delivery and a lack of confidence in being able to script the relevant chemistry correctly. Consideration for further research might be given to this and the impact of the differences between students writing their own scripts as opposed to using scripts provided for them.

Further research might focus on whether or not there are common traits between students who reported similar opinions regarding the usefulness of simulation-role-play in helping to recall and/or understand the relevant chemistry, e.g. personality type.

It might also be useful for subsequent research to focus upon the role of teachers in the implementation of simulation-role-play as a classroom pedagogy in a science lesson and any school-based barriers to its use in science lessons. Although the focus of this study was the gathering of quantitative and qualitative data from students, informal conversations with host teachers also took place while the researcher was in school. Some chemistry teachers were very interested in the use of drama in their classroom but felt they lacked the skills to design and manage this type of lesson. Other chemistry teachers were, similarly, interested in drama but expressed concerns regarding the amount of time it would take out of lessons. Other chemistry teachers were, by contrast, unwilling to entertain the use of drama in their A Level lessons. Based on the findings of this study, there may be value in providing training for science teachers willing to engage in the use of drama for their science lessons. This supports McGregor's work (2012) where the training of teachers in the use of drama techniques to teach science topics, in advance of using them in their classroom, raised their confidence as practitioners in using and applying the techniques to a range of contexts.

Whilst not advocating the use of simulation-role-play in every lesson, the researcher has concluded, based upon the findings of this study, that simulation-role-play has a place in the pedagogical repertoire of those involved in the teaching of chemistry within the science classroom or laboratory. This study has indicated that, for this chemistry topic, students do at least as well when answering authentic A Level Chemistry questions than if they had done alternative work answering examination-style questions. Moreover, what has been shown is that students gained a deeper understanding of the topic when they used simulation-role-play and that they did so to a greater extent when they wrote their own scripts. It must be added, that students who had been allocated to the drama group clearly articulated that even though they generally felt the use of drama to have assisted their learning they still wanted a variety of teaching and learning strategies. Whilst the students in the drama group appreciated the pedagogical approach that they had experienced, they also still valued the use of practice examination questions to hone their exam technique and to help achieve the grades towards which they were aspiring.

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List of Abbreviations and Definitions

A Level: Advanced, subject-based, level 3 qualification, usually studied over two years. Sometimes also referred to as GCE or GCE A Level.

Alps: A Level performance system. A system designed to predict A Level grades, for individual students, by means of comparison to benchmark data set of achievement.

AO: Assessment objectives.

AQA: Assessment and Qualifications Alliance examination board for GCE and GCSE qualifications.

EPF: electron-pushing formalisation. A method of representing the movement of electrons in a chemical reaction as curly arrows.

Further education: Upon completion of secondary education, students may enter further education in order to extend their learning, often in preparation for university or college. At this stage they may select to study for A Level qualifications.

GCE: General Certificate of Education, synonymous with A Level.

GCSE: General Certificate of Secondary Education in England, Wales and Northern Ireland. An externally assessed qualification, usually awarded at the end of KS4.

KS2: Key Stage 2. Junior school (students aged 7-11).

KS3: Key Stage 3. Lower secondary school (students aged 11-14).

KS4: Key Stage 4. Upper secondary school (students aged 14-16).

KS5: Key Stage 5. Post secondary phase of education, pre-university (Students aged 16-18)

OCR: Oxford, Cambridge and RSA examination board.

Ofqual: Office of Qualifications and Examinations Regulation

Pearson Edexcel: Edexcel examination board for GCSE and GCE qualifications.

Post-intervention assessment items: The past examination questions answered, approximately two weeks after an intervention, by all students taking part in the study. These were used in Phases 1, 2 and 3 of the study.

SCORE: Science Community Representing Education. A partnership of 7 organisations aimed at improving science education.

Secondary education: Mandatory education for pupils aged 11-16. This is divided into two sections: Key Stage 3, for pupils aged 11-14, and Key Stage 4, for pupils aged 14-16.

STEM: Science, Technology, Engineering and Mathematics

Student: Learner aged 4-18 in school or college education. This encompasses KS2, KS3, KS4 and KS5 in the education system in England, Wales and Northern Ireland.

Undergraduate: Learner in higher education, studying for a university degree.

Y1: First year of the A Level qualification.

Y2: Second year of the A Level qualification.

Appendix A
Teaching and Learning Resources

A.1 Lesson resources for Phases 1 and 2

A.1.1 Lesson plan for drama group, Phase 1

<table>
<tr><th colspan="2"><u>Lesson plan, drama group, Phase 1</u></th></tr>
<tr><td><u>Subject and title of scheme</u></td><td>AS Nucleophilic substitution for AQA and OCR A, OCR B (Salters) and Pearson Edexcel</td></tr>
<tr><td><u>Learning objectives</u>
Understand that haloalkanes (halogenoalkanes) contain polar bonds.
Understand that haloalkanes (halogenoalkanes) are susceptible to nucleophilic attack by OH^-, CN^- and NH_3 (AQA), hot aqueous alkali and H_2O (OCR,) OH^-, H_2O and NH_3(OCR B), alcoholic KOH, alcoholic ammonia, aqueous alkali (Pearson Edexcel).
Understand the mechanism of nucleophilic substitution in primary haloalkanes.</td><td><u>Lesson outcomes -</u> how successful learning is demonstrated
Be able to correctly identify bond polarities in a range of haloalkanes.
Be able to define nucleophile and identify examples.
Write correct reaction mechanisms, using “curly arrows” for a range of nucleophilic substitution reactions.</td></tr>
<tr><td colspan="2"><u>Barriers to learning</u>
Students will need previous knowledge relating to electronegativity, bond polarity, covalent bonding and drawing displayed organic structures.</td></tr>
<tr><td colspan="2"><u>Equipment / resources required</u>
Name labels (one per student)
Black felt tipped pens
Happy Families cards – enough sets to work 4 to a group
Cards with names of reagents on them (bromoethane, 1-bromopropane, bromomethane)
Cards with names of nucleophiles on them OH^-, CN^-, NH_3, H_2O
Rulers with Velcro on</td></tr>
</table>

• Cards with + or – on them • Small fabric balls to stick on the Velcro (to represent electrons) • δ+, δ⁻ cards • Velcro • String • Coloureds felt tipped pens • Drama script sheets • Evaluation sheet • Sheets of A3 paper/flip chart paper
Health and safety issues Ensure working area for drama is clear of obstacles

Lesson content, drama group, Phase 1		
Planned timings (mins)	**Researcher activity**	**Student activity**
5	• Introduce self and purpose of this lesson. • Students write name badges.	
10	**Starter** • Students complete Happy Families activity to review knowledge of previous learning. • Check answers, teacher-led Q&A to consolidate.	• Students work in groups of 3 or 4 to complete happy families.
15	**Main learning phase(s) and AfL** **Introduction to new theory** • Draw up structure for 1-bromoethane on the board. • Using the following questions researcher gradually draws out the information to complete the mechanism on the board in different	• Students answer questions and direct researcher on what to write on the board.

	coloured pens whilst at the same time getting students to come up to the front and 'act out' the simulation-role-play using the kit provided. Constant links will be made between the 3D and 2D representations. **Key questions/concepts to be demonstrated** • What is this molecule called? • Which bond/s in this molecule are polar? • Identify the polarity. • In your books draw out the structure for a hydroxide ion. • How would a hydroxide ion behave when brought close to the bromoethane? • Show how the hydroxide ion contains a lone pair of electrons and is attracted to the partial positive charge on the carbon identified above. • Show attack of the lone pair of hydroxide electrons to form a new covalent bond and the breaking of the carbon/bromine bond, leading to the formation of a bromide ion. Explain why the bromine is now bromide (having gained an 'extra' electron).	

	Second example • Repeat this process for the reaction of bromomethane with water as the nucleophile introducing the terms nucleophile and leaving group. Also include the loss of H^+ in this mechanism (started with a neutral instead of a negative nucleophile). Again, link the simulation-role-play at the front of the class to the 2D representation. **Key points to be raised in the teaching** • Definition of a nucleophile. • A species (ion or molecule) with a lone pair of electrons that is available to form a coordinate bond (covalent bond in which both electrons come from one species). Nucleophiles are attracted to regions of positive charge (areas of electron deficiency). • Emphasise the key features of curly arrows (representing the **movement** of electrons from areas of high electron density to areas of low electron density. Double headed arrow indicates the movement of two electrons).	

	• Explain what a reaction mechanism is (a means of showing a **series of movements of electrons allowing a logical reaction pathway to be visualised).**	
25	**Demonstration of learning** • Introduce the task. • Students are to enact their own simulation-role-play to represent the reaction/s they have been allocated using the props and script provided. 9they have already seen how to use the props in the introduction to new theory section of the lesson). • A general reaction mechanism and a list of key points the simulation-role-play will need to represent have been provided for each student. • Working in self-selected groups of 4/5, students are given 10 minutes to practice/refine their simulation-role-play. • Each group also writes down their reaction mechanism on a sheet of A3 paper, including identification of the nucleophile and the leaving group.	 • Students work in groups of 4 or 5 to produce their simulation-role-play given their own set of reaction conditions.

	• Each mechanism on the worksheet is acted out as a simulation-role-play by the group allocated that mechanism, including displaying the mechanism they have drawn out. • All students complete a reaction mechanism on the worksheet provided for the reaction/s they observe being performed and then complete the remaining examples on the worksheet.	• Students enact and/or watch the simulation-role-plays and complete worksheets to ensure they have reaction mechanisms for each type of nucleophile. • This ensures that mechanisms for each type of nucleophile have been completed as notes.
5	Explain the purpose of the research. Explain that I will be leaving examination-style questions for completion in approx. 2 weeks and, for those who give consent, a questionnaire and possible participation in a group discussion.	

A.1.2 Lesson plan for drama group, Phase 2

<table>
<tr><th colspan="2">Lesson plan, drama group, Phase 2</th></tr>
<tr><td>Subject and title of scheme</td><td>AS Nucleophilic substitution for AQA and OCR A, and Pearson Edexcel</td></tr>
<tr><td>Learning objectives
• Understand that haloalkanes (halogenoalkanes) contain polar bonds.
• Understand that haloalkanes (halogenoalkanes) are susceptible to nucleophilic attack by OH^-, CN^-(AQA), hot aqueous alkali and H_20(OCR) OH^- alcoholic KOH, aqueous alkali (Pearson Edexcel).
• Understand the mechanism of nucleophilic substitution in primary haloalkanes.</td><td>Lesson outcomes - how successful learning is demonstrated
• Be able to correctly identify bond polarities in a range of haloalkanes.
• Be able to define nucleophile and identify examples.
• Write correct reaction mechanisms, using “curly arrows” for a range of nucleophilic substitution reactions.</td></tr>
<tr><td colspan="2">Barriers to learning
Students will need previous knowledge relating to electronegativity, bond polarity, covalent bonding and drawing displayed organic structures.</td></tr>
<tr><td colspan="2">Equipment / resources required
• Name labels (one per student)
• Black felt tipped pens
• Cards with names of reagents on them (bromoethane, 1-bromopropane, bromomethane)
• Cards with names of nucleophiles on them OH^-, CN^-
• Rulers with Velcro on
• Cards with + or – on them
• Small fabric balls to stick on the Velcro (to represent electrons)
• $\delta+$, δ^- cards
• Velcro
• String
• Coloureds felt tipped pens
• Drama script sheets
• Evaluation sheet
• Sheets of A3 paper/flip chart paper</td></tr>
</table>

Health and safety issues
Ensure working area for drama is clear of obstacles.

Lesson content, drama group, Phase 2		
Planned timings (mins)	**Researcher activity**	**Student activity**
5	• Introduce self and purpose of this lesson. • Students write name badges.	
15	**Main learning phase(s) and AfL** **Introduction to new theory** • Draw up structure for 1-bromoethane on the board. • Using the following questions researcher gradually draws out the information to complete the mechanism on the board in different coloured pens whilst at the same time getting students to come up to the front and 'act out' the simulation-role-play using the kit provided. Constant links will be made between the 3D and 2D representations. **Key questions/concepts to be demonstrated** • What is this molecule called? • Which bond/s in this molecule are polar? • Identify the polarity. • In your books draw out the structure for a hydroxide ion.	• Students answer questions and direct researcher on what to write on the board.

	• How would a hydroxide ion behave when brought close to the bromoethane? • Show how the hydroxide ion contains a lone pair of electrons and is attracted to the partial positive charge on the carbon identified above. • Show attack of the lone pair of hydroxide electrons to form a new covalent bond and the breaking of the carbon/bromine bond, leading to the formation of a bromide ion. Explain why the bromine is now bromide (having gained an 'extra' electron). **Key points to be raised in the teaching** • Definition of a nucleophile. • A species (ion or molecule) with a lone pair of electrons that is available to form a coordinate bond (covalent bond in which both electrons come from one species). Nucleophiles are attracted to regions of positive charge (areas of electron deficiency). • Emphasise the key features of curly arrows (representing the **movement** of electrons from areas of high electron density to areas of low electron density. Double headed arrow indicates the movement of two electrons).	

	• Explain what a reaction mechanism is (a means of showing a series of movements of electrons allowing a logical reaction pathway to be visualised).	
25	**Demonstration of learning** • Introduce the task. • Students are to enact their own simulation-role-play to represent the reaction/s they have been allocated using the props and script provided. 9they have already seen how to use the props in the introduction to new theory section of the lesson). • A general reaction mechanism and a list of key points the drama will need to represent have been provided for each student. • Working in self-selected groups of 4/5, students are given 10 minutes to practice/refine their drama. • Each group also writes down their reaction mechanism on a sheet of A3 paper, including identification of the nucleophile and the leaving group.	• Students work in groups of 4 or 5 to produce their simulation-role-play given their own set of reaction conditions.
	• Each mechanism on the worksheet is acted out as a simulation-role-play by the group allocated that mechanism, including displaying the mechanism they have drawn out.	• Students enact and/or watch the simulation-role-plays and complete worksheets to ensure they have

	• All students complete a reaction mechanism on the worksheet provided for the reaction/s they observe being performed and then complete the remaining examples on the worksheet.	reaction mechanisms for each type of nucleophile. This ensures that mechanisms for each type of nucleophile has been completed as notes.
10	• Students complete Q3 and check answers against the mark scheme provided.	• Students work individually to answer questions then self-mark.
5 If enough time, otherwise leave information with host teacher	• Explain the purpose of the research. • Explain that I will be leaving examination-style questions for completion in approx. 2 weeks and, for those who give consent a questionnaire and future focus group.	

A.1.3 Lesson plan for examination-style question group, Phase 1

Lesson plan, examination-style question group, Phase 1	
Subject and title of scheme	AS Nucleophilic substitution for AQA and OCR A, OCR B(Salters) and Pearson Edexcel
Learning objectives • Understand that haloalkanes contain polar bonds. • Understand that haloalkanes are susceptible to nucleophilic attack by OH^-, CN^-, NH_3(AQA), hot aqueous alkali, H_2O (OCR) OH^-, H_2O, NH_3 (OCR B), alcoholic KOH, alcoholic ammonia, aqueous alkali (Pearson Edexcel). • Understand the mechanism of nucleophilic substitution in primary haloalkanes.	**Lesson outcomes - how successful learning is demonstrated** • Be able to correctly identify bond polarities in a range of haloalkanes. • Be able to define nucleophile and identify examples. • Write correct reaction mechanisms, using “curly arrows” for a range of nucleophilic substitution reactions.
Barriers to learning Students will need previous knowledge relating to electronegativity, bond polarity, covalent bonding and drawing displayed organic structures.	
Equipment / resources required • Name cards (one per student) • Black felt tipped pens • Happy Families cards – enough sets to work 4 to a group • Exam questions/text book questions and mark schemes (one set per student)	
Health and safety issues nil	

Lesson content, examination-style question group, Phase 1		
Planned timings (mins)	**Researcher activity**	**Student activity**
5	• Introduce self and purpose of this lesson. • Students write name badges.	
10	**Starter** • Students complete happy families activity to review knowledge of previous learning.	• Students work in groups of 3 or 4 to complete happy families. • Check answers, teacher-led Q&A to consolidate.
10	**Main learning phase(s) and AfL** **Introduction to new theory** • Draw up structure for 1-bromoethane on the board. • Using the following questions, the researcher gradually draws out the information to complete the mechanism on the board in different coloured pens. **Key questions to allow new learning to be accessed** • What is this molecule called? • Which bond/s in this molecule are polar? • Identify the polarity. • In your books draw out the structure for a hydroxide ion.	• Students answer questions and direct on what to write on the board. • Students copy complete mechanisms into their notebook.

	• How would a hydroxide ion behave when brought close to the bromoethane? • Show how the hydroxide ion contains a lone pair of electrons and is attracted to the partial positive charge on the carbon identified above. • Show attack of the lone pair of hydroxide electrons to form a new covalent bond and the breaking of the carbon/bromine bond, leading to the formation of a bromide ion. Explain why the bromine is now bromide (having gained an 'extra' electron). **Second example** • Go back to the beginning of the reaction and repeat using ammonia as the nucleophile introducing the terms nucleophile and leaving group. Also include the loss of H^+ in this mechanism (started with a neutral instead of a negative nucleophile). **Key points to be raised in the teaching** • Definition of a nucleophile. • A species (atom, ion or molecule) with a lone pair of electrons that is available to form a coordinate bond (covalent bond in which both electrons come from one species). Nucleophiles are attracted to regions of positive charge areas of electron deficiency).	

	• Emphasise the key features of curly arrows (representing the **movement** of curly arrows from areas of high electron density to areas of low electron density. Double headed arrow indicates the movement of two electrons). • Explain what a reaction mechanism is (a means of showing a series of movements of electrons allowing a logical reaction pathway to be visualised).	
25	**Demonstration of learning** • Introduce the task. • Instruct students to work through examination-style questions from text books/examination papers. Questions provided and pre-printed.	• Students work individually to answer questions, may talk with other students in their group or ask for assistance from teacher.
	• Students self-mark using the mark scheme provided.	• Students mark work, asking for assistance from other students and/or teacher if needed.
5	• Explain the purpose of the research. • Explain that I will be leaving examination-style questions for completion in approx. 2 weeks and, for those who give consent a questionnaire and possible participation in a discussion group.	

A.1.4 Lesson plan for examination-style question group, Phase 2

<table>
<tr><th colspan="2"><u>Lesson plan, examination-style question group, Phase 2</u></th></tr>
<tr><td><u>Subject and title of scheme</u></td><td>AS Nucleophilic substitution for AQA and OCR and Pearson Edexcel.</td></tr>
<tr><td><u>Learning objectives</u>

• Understand that haloalkanes contain polar bonds.

• Understand that haloalkanes are susceptible to nucleophilic attack by OH^-, CN^- (AQA), hot aqueous alkali, H_2O (OCR), alcoholic KOH (Pearson Edexcel).

• Understand the mechanism of nucleophilic substitution in primary haloalkanes.</td><td><u>Lesson outcomes</u> - how successful learning is demonstrated

• Be able to correctly identify bond polarities in a range of haloalkanes.

• Be able to define nucleophile and identify examples.

• Write correct reaction mechanisms, using “curly arrows” for a range of nucleophilic substitution reactions.</td></tr>
<tr><td colspan="2"><u>Barriers to learning</u>

Students will need previous knowledge relating to electronegativity, bond polarity, covalent bonding and drawing displayed organic structures.</td></tr>
<tr><td colspan="2"><u>Equipment / resources required</u>
• Name cards (one per student)
• Black felt tipped pens
• Exam questions/text book questions and mark schemes (one set per student)</td></tr>
<tr><td colspan="2"><u>Health and safety issues</u>

nil</td></tr>
</table>

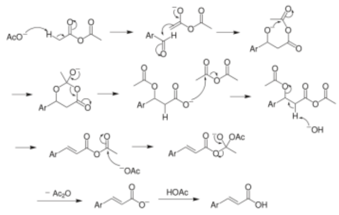
Lesson content, examination-style question group, Phase 2		
Planned timings (mins)	**Researcher activity**	**Student activity**
5	• Introduce self and purpose of this lesson. • Students write name badges.	
10	**Main learning phase(s) and AfL** **Introduction to new theory** • Draw up structure for 1-bromoethane on the board. • Using the following questions, the researcher gradually draws out the information to complete the mechanism on the board in different coloured pens. **Key questions to allow new learning to be accessed** • What is this molecule called? • Which bond/s in t is molecule are polar? • Identify the polarity. • In your books draw out the structure for a hydroxide ion. • How would a hydroxide ion behave when brought close to the bromoethane? • Show how the hydroxide ion contains a lone pair of electrons and is attracted to the partial positive charge on the carbon identified above.	• Students answer questions and direct on what to write on the board. • Students copy complete mechanisms into their notebook.

	• Show attack of the lone pair of hydroxide electrons to form a new covalent bond and the breaking of the carbon/bromine bond, leading to the formation of a bromide ion. Explain why the bromine is now bromide (having gained an 'extra' electron) instead of a negative nucleophile. **Key points to be raised in the teaching** • Definition of a nucleophile. • A species (atom, ion or molecule) with a lone pair of electrons that is available to form a coordinate bond (covalent bond in which both electrons come from one species). Nucleophiles are attracted to regions of positive charge areas of electron deficiency). • Emphasise the key features of curly arrows (representing the **movement** of curly arrows from areas of high electron density to areas of low electron density. Double headed arrow indicates the movement of two electrons). • Explain what a reaction mechanism is (a means of showing a series of movements of electrons allowing a logical reaction pathway to be visualised).	

25	**Demonstration of learning** • Introduce the task. • Instruct students to work through examination-style questions from text books/examination papers. Questions provided pre-printed.	• Students work individually to answer questions, may talk with other students in their group or ask for assistance from teacher.
	• Students self-mark using the mark scheme provided.	• Students mark work, asking for assistance from other students and/or teacher if needed.
10	• Students complete Q3 and check answers against the mark scheme provided.	• Students work individually to answer questions then self-mark.
5	• Explain the purpose of the research. • Explain that I will be leaving examination-style questions for completion in approx. 2 weeks and, for those who give consent a questionnaire and possible participation in a discussion group.	

A.1.5 PowerPoint slides for the drama and the examination-style question group lessons, Phases 1 and 2

Organic reaction mechanisms
Nucleophilic substitution



Slide 1

Outcomes for this lesson

- be able to correctly identify bond polarities in a range of haloalkanes (halogenoalkanes)
- be able to define nucleophile and identify examples
- write correct reaction mechanisms, using "curly arrows" for a range of nucleophilic substitution reactions

Slide 2

reaction mechanism

A means of showing a series of movements of electrons allowing a logical reaction pathway to be visualised.

Curly arrows representing the movement of electrons from areas of high electron density to areas of low electron density. Double headed arrow indicates the movement of two electrons.

Slide 3

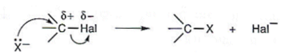
Nucleophile

- A species (atom, ion or molecule) with a lone pair of electrons that is available to form a coordinate/dative bond (covalent bond in which both electrons come from one species).
- Nucleophiles are attracted to regions of positive charge(areas of electron deficiency)

Slide 4

Nucleophilic substitution

- A reaction in which a nucleophile attacks an electron deficient atom, donates a lone pair of electrons forming a new dative covalent bond, displacing a leaving group.



Slide 5

A.1.6 Happy Families cards used in drama and examination-style question groups, Phase 1

single covalent bond	δ^-
δ^+	partial positive charge
partial negative charge	electronegativity
halogen	X
Cl, Br	Polar bond

Uneven distribution of charge in a bond	H-Cl
—	2 electrons
	Lone pair of electrons
unbonded electrons	• •

A.1.7 Sample script for drama group lesson, Phase 1

<u>The reaction of warm chloroethane with ethanolic potassium cyanide solution</u>

<***person 1*** *walks onto the stage, with a sign giving the reaction and reads this out*>

<*scene opens with chloroethane*>

C and **Cl** Hello, together we are chloroethane

Cl I'm chlorine and I am part of a haloalkane (halogenoalkanes). I've formed a covalent bond with carbon. Because I'm more electronegative than carbon here I have the greatest share of the two electrons in our bond *<move 'electrons' (felt balls) along the 'bond' (ruler) towards the Cl end of the bond>.*

C I'm carbon, part of an ethyl group, I have formed a single covalent bond with chlorine *<point to the two 'electrons' on the ruler>.* As you can see, chlorine is more electronegative than me, and has a greater share of the electrons. This means that I am partially positive <*stick δ + sign on C label*> and s/he is partially negative <*stick δ^- sign on Cl sign*>.

CN^- < *walk onstage, holding a ruler*> Hello, I am a cyanide ion, one of many. We are in solution with potassium ions, but I'm my own ion, I function independently of them. I am special. I am a **nucleophile**. <***person 1*** *holds up nucleophile sign*> You can see I have a beautiful lone pair of electrons. <*point to 'electron' felt balls on CN^- card*> This means I am attracted to that carbon over there. See how s/he is lacking electrons. I could share mine with him/her and create a new dative covalent bond. I'm going to attack just there……… <*point to the δ+ sign on C*>

CN^-<*take the 'lone pair of electrons' and stick onto a ruler, offering them to the electron deficient carbon.*>

C I think I will form a new bond with this nucleophile. Both the electrons will come from him/her. However, I will then have too many electrons. I know, as I make this new bond, I will get rid of the bond with chlorine. S/he can have both electrons. It's the least I can do, since I am getting rid of him/her.

<*grasp hold of the new 'bond' from CN and, at the same time, leave go of the existing bond with Cl*> I can't keep both of them, I'm not that kind of carbon!!!!!

Cl <*keeping hold of the ruler 'bond' transfer both electrons from the 'broken C-Cl bond on to the Velcro of the Cl label*> Another broken bond, the story of my life!!!! Still, I've now got the electron I originally put into the bond with carbon, plus the one carbon originally supplied. This means that overall I have a negative charge now. <*stick negative charge onto Cl label*>. <*move away from the new molecule*> I have left the molecule now; I am my own ion. With this negative charge I am now known as a **chloride** ion. I am the **LEAVING GROUP**. <***person 1*** *hold up the leaving group sign*>

Person 1 This new molecule is a NITRILE. (It is actually called propanenitrile, but you don't need to remember this.) Because the cyanide ion is a *nucleophile* and it has *substituted* for the chlorine, this type of reaction is called a **nucleophilic substitution** reaction. When a haloalkane (halogenoalkanes) reacts with a cyanide ion in this way a nitrile is formed.

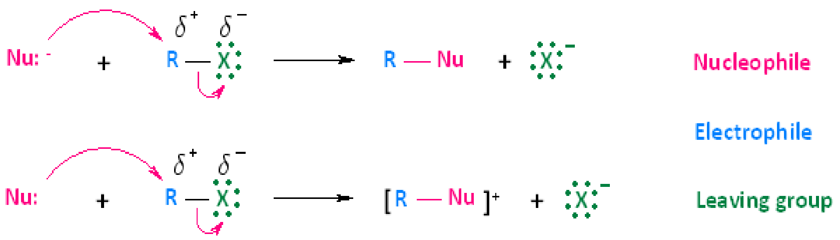
A.1.8 Guidance notes for drama group Phases 1 and 2

Guidance notes

When presenting your drama you will be representing the main steps involved in a nucleophilic substitution reaction

Generic stages in nucleophilic substitution reaction

- The **electron deficient** carbon atom in a carbon-halogen bond is attacked by an electron rich species known as a **nucleophile**
- The nucleophile is a molecule or ion with a lone pair of electrons that it donates to form a new covalent dative bond with the electron deficient carbon
- The covalent bond between the carbon and halogen breaks heterolytically, with both electrons transferring to the halogen, producing a halide ion. (referred to as the **leaving group**) (remember if the attacking nucleophile is a neutral molecule there will be a further step involved with the loss of H^+).



- Because the reaction involves a nucleophile replacing a leaving group this type of reaction is called a nucleophilic substitution reaction

In order to clearly represent your reaction, you need to include the following in your drama

1. Identification of the bond polarities needed to understand this reaction
2. Clear identification of the nucleophile
3. Arrows representing the movement of electrons from areas of high electron density to areas of low electron density
4. Electron movement to show how the leaving group is formed
5. Any charges on nucleophiles and/or leaving group

A.1.9 Student note sheets for drama group, Phases 1 and 2

(Note that examples involving water and ammonia as the nucleophile were not used during Phase 2.)

Teaching demonstration

<table>
<tr><td colspan="2">Reaction/ conditions:
Bromoethane (dissolved in ethanol) heated with dilute sodium hydroxide solution</td></tr>
<tr><td colspan="2">Reaction mechanism</td></tr>
<tr><td colspan="2">Overall balanced equation for the reaction:</td></tr>
<tr><td>Nucleophile:</td><td>Leaving group:</td></tr>
</table>

Teaching demonstration

Reaction/ conditions	
Bromomethane (in ethanol) heated under reflux with water	
Reaction mechanism	
Overall balanced equation for the reaction:	
Nucleophile:	Leaving group:

Reaction/ conditions **Chloroethane heated with ethanolic potassium cyanide**	
Reaction mechanism	
Overall balanced equation for the reaction:	
Nucleophile:	Leaving group:

Reaction/ conditions: **Heating iodopropane in a sealed tube with excess ammonia**	
Reaction mechanism	
Overall balanced equation for the reaction:	
Nucleophile:	Leaving group:

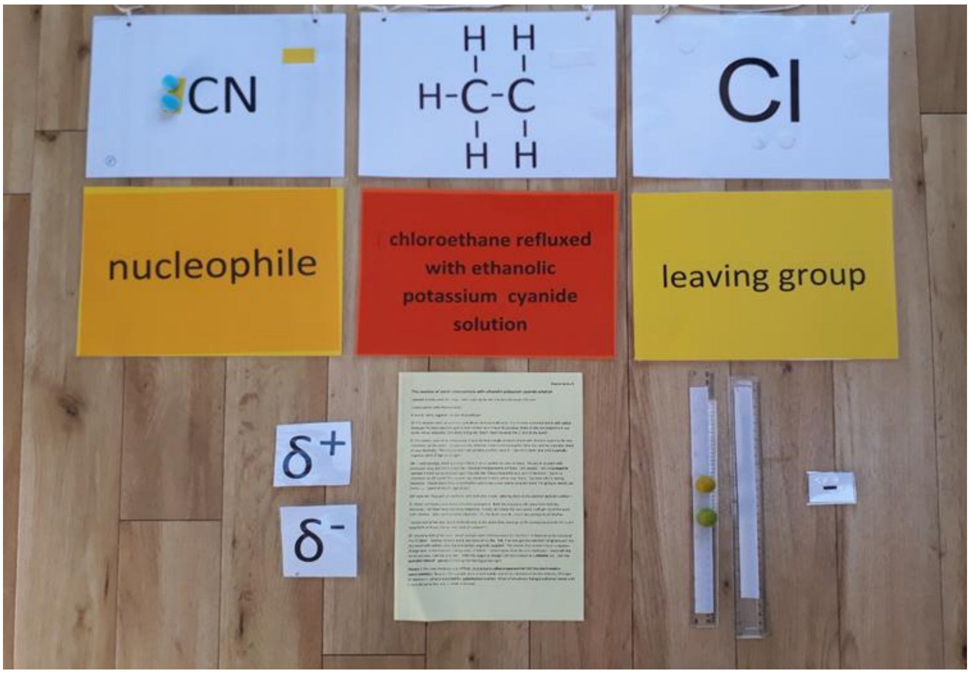
Reaction/ conditions: **Reflux ethanolic sodium hydroxide solution with 1-chloropropane**	
Reaction mechanism	
Overall balanced equation for the reaction:	
Nucleophile:	Leaving group:

Reaction/ conditions: **Refluxing 1-iodobutane in ethanol with water**	
Reaction mechanism	
Overall balanced equation for the reaction:	
Nucleophile:	Leaving group:

Reaction/ conditions: **Heating chloromethane in a sealed tube with excess ammonia**	
Reaction mechanism	
Overall balanced equation for the reaction:	
Nucleophile:	Leaving group:

Reaction/ conditions: **Heating ethanolic potassium cyanide with chloroethane**	
Reaction mechanism	
Overall balanced equation for the reaction:	
Nucleophile:	Leaving group:

A.1.10 Photograph of sample drama kit, Phases 1 and 2

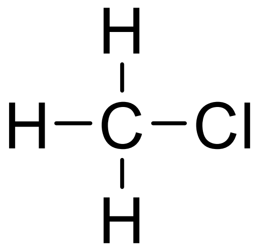


A.1.11 Examination-style question class questions, Phases 1 and 2

The questions below were used in Phase 1. In Phase 2 the questions relating to the use of ammonia and water as nucleophiles were removed (2d, 3 iii., 4 and the section in Q5 with $CH_3CH(NH_2)CH_3$ as the product). Also, during Phase 2, question 3 (parts 1 and 2) was used as the common question following the drama.

1.Haloalkanes (halogenoalkanes) are polar molecules and react with nucleophiles.

a. The displayed formula for chloromethane is shown below. Label the dipole on the C-Cl bond. (1 mark)



b. Chloromethane is hydrolysed by aqueous sodium hydroxide in a nucleophilic substitution reaction. An equation for this is shown below.

$CH_3Cl + OH^- \longrightarrow CH_3OH + Cl^-$

i. What is meant by the term nucleophile? (2 marks)

ii. Explain why haloalkanes (halogenoalkanes) are readily attacked by nucleophiles. (2 marks)

iii. Show with the aid of curly arrows, the mechanism for the hydrolysis shown earlier in this question. (3 marks)

2. When 1-chloropropane is heated under reflux with aqueous sodium hydroxide solution, a nucleophilic substitution reaction occurs, forming propan-1-ol.

a. Write a full balanced equation to show the overall reaction.
(1 mark)

b. Explain why this is classified as a substitution reaction
(1 mark)

c. Write down the structure of the attacking nucleophile, showing the charge and any lone pairs of electrons.
(2 marks)

d. Even though water is not negatively charged it can act as a nucleophile. Using a diagram to assist, explain why this is the case. (2 marks)

3. For each of the following pairs of compounds:

a. Write an equation for the reaction (1 mark each)
b. Give the reaction conditions (2 marks each)
c. Name the organic product in the reaction (1 mark each)
d. Outline the mechanism for the reaction. (3 marks each)

i. $CH_3CH_2CH_2Br$ and KOH

ii. $CH_3CH_2CH_2CH_2I$ and KCN

iii. CH_3CH_2Cl and NH_3

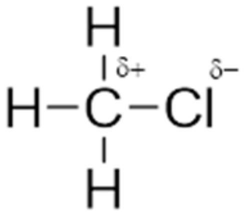
4. Show a full reaction mechanism for the hydrolysis of chloroethane with water. (3 marks)

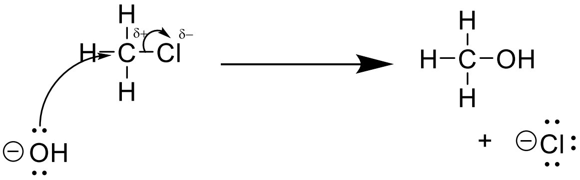
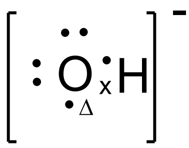
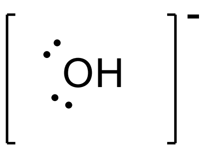
5. Complete the table below by suggesting the structure of the starting haloalkane (halogenoalkane), reagents and conditions needed to synthesise each of the products in the table.

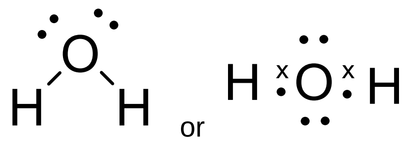
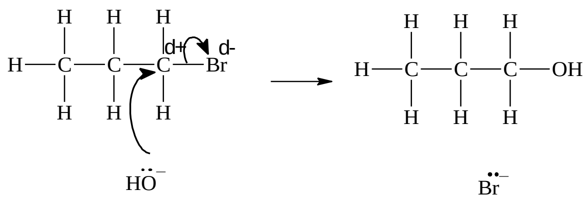
<table>
<tr><th>Product</th><th>Structure of halogenoalkane</th><th>Reagents</th><th>Conditions</th></tr>
<tr><td rowspan="2">$CH_3CH_2CH_2CH_2CH_2OH$</td><td rowspan="2"></td><td></td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td>$CH_3CH(NH_2)CH_3$</td><td></td><td></td><td></td></tr>
<tr><td>$CH_3CH_2CH_2CN$</td><td></td><td></td><td></td></tr>
</table>

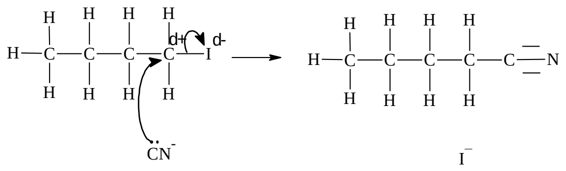
(11 marks, 1 per correct box)

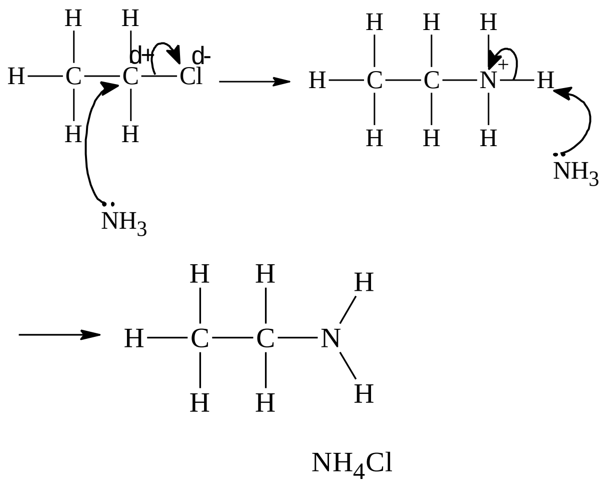
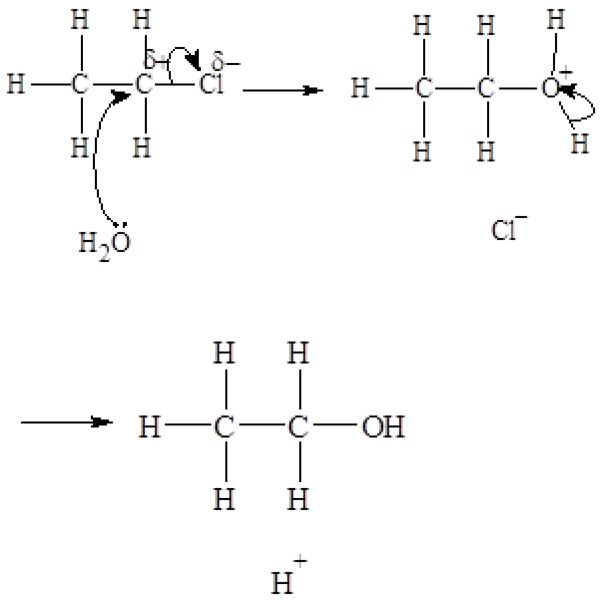
A.1.12 Answers to the questions used in the examination-style question group lesson, Phases 1 and 2

Question number		Answer	Comments
1	a	 (1 mark)	Correct use of both δ^+ and δ^- needed for the mark
	b)i)	A molecule or negatively charged ion with a lone pair of electrons (1 mark) that it can be donated to a positively charged atom to form a new (dative) covalent bond (1 mark)	Both parts for one mark Both parts for the second mark. Dative not necessary
	b)ii)	The carbon-halogen bond is polarised/the carbon in the carbon halogen bond is (partially) positively charged (1 mark) This is therefore susceptible to attack by the negatively charged lone pair of electrons of the nucleophile (1 mark)	Some indication of δ+ on the carbon bond in the C-X needed for first mark Some reference to opposite charge on the lone pair of electrons of the nucleophile for second mark

	b)iii)	 (3 marks)	1 mark for correct positioning of arrow showing the attacking nucleophile (**from** lone pair of electrons **to** the central carbon) 1 mark for the arrow showing the movement of electrons **from** the C-Cl bond **to** the Cl 1 mark for correct products
2.	a	$CH_3CH_2CH_2Cl + NaOH \longrightarrow CH_3CH_2CH_2OH + NaCl$ (1 mark)	All correct for the mark
	b	The hydroxide ion substitutes for/replaces the chlorine in the reaction	1 mark Or words to that effect
	c	 or  (2 marks)	1 mark for lone pair of electrons on the OH 1 mark for negative charge

	d.	 (1 mark) One of the lone pair of electrons can be used to donate to a positively charged atom to form a new (dative) covalent bond (i.e. acts as a nucleophile) (1 mark)	1 mark for lone pairs on the O of the water and rest of molecule correct 1 mark for describing the behaviour of the lone pairs
3	i)a)	$CH_3CH_2CH_2Br + KOH \longrightarrow CH_3CH_2CH_2OH + KBr$ (1 mark)	Accept OH^- instead of KOH and Br^- instead of KBr
	i)b)	Dissolve 1-bromopropane/haloalkane/halogenoalkane and potassium hydroxide in ethanol (1 mark) Warm/heat (1 mark)	
	i)c)	propan-1-ol (1 mark)	Do not accept butanol
	i)d)	 (3 marks)	Correct bond polarities (1 mark) Correct positioning and direction of arrow to show attack of nucleophile (1 mark) Correct positioning and direction of arrow producing the leaving group (1 mark)
	ii)a)	$CH_3CH_2CH_2\ CH_2I + KCN \longrightarrow CH_3CH_2CH_2\ CH_2CN + KI$ (1 mark)	Accept CN^- instead of KCN and Br^- instead of KBr
	ii)b)	Dissolve the haolalkane/halogenoalkane/1-bromobutane and potassium ctanide in ethanol (1 mark) Warm/heat (1 mark)	
	ii)c)	pentanenitrile (1 mark)	

	ii)d)	 (3 marks)	Correct bond polarities (1 mark) Correct positioning and direction of arrow to show attack of nucleophile (1 mark) Correct positioning and direction of arrow producing the leaving group (1 mark)
	iii)a)	$CH_3CH_2Cl + NH_3 \longrightarrow CH_3CH_2NH_2 + H^+$ All correct (1 mark)	Needs to be balanced
	iii)b)	Heat the chloroethane/haloalkane/halogenoalkane in a sealed tube (1 mark) with **excess** ammonia (1 mark)	
	iii)c)	Ethylamine (1 mark)	

	iii)d)	 (3 marks)	Correct attack by lone pair of electrons on the N and breaking of Cl bond to release Cl^- (1 mark) Correct structure and charge on the intermediate (N^+) (1 mark) Reaction of second NH_3 acting to remove H^+ to give NH_4^+
4			Correct attack by lone pair of electrons and loss of chloride ion (1 mark) Correct intermediate with + on the O, correct movement of electrons to remove H^+ (1 mark) Correct final product i.e. alcohol, H^+ and Cl^- (1 mark)

Question No. 5			
Product	**Structure of halogenoalkane**	**Reagents**	**Conditions**
$CH_3CH_2CH_2CH_2CH_2OH$	$CH_3CH_2CH_2CH_2CH_2X$ Where X is Cl, Br or I	Named haloalkane/ halogenoalkane (prefix pent) and either sodium or potassium hydroxide	Dissolve in ethanol and heat
		Named haloalkane/ halogenoalkane (prefix pent) and water	Dissolve in ethanol and heat
$CH_3CH(NH_2)CH_3$	CH_3CHXCH_3 Where X is Cl, Br or I	Named haloalkane/halogenoalkane (prefixed prop) and excess ammonia	Heat in a sealed tube
$CH_3CH_2CH_2CN$	$CH_3CH_2CH_2X$ Where X is Cl, Br or I	Named haloalkane(halogenoalkane) (prefix prop) and either sodium cyanide or potassium cyanide	Dissolve reagents in ethanol and heat
			(11 marks, one per completely correct box)

A.2 Lesson resources for Phase 3

A.2.1 Lesson plan for drama group, Phase 3

Phase 3 Lesson plan drama group	
Subject and title of scheme	Nucleophilic addition for AQA and OCR A and Pearson Edexcel
Learning objectives • Outline the nucleophilic addition mechanism for reduction reactions with $NaBH_4$(AQA and OCR A) $LiAlH_4$ in dry ether (Pearson Edexcel) (the nucleophile should be shown as H^-). • Write overall equations for the formation of hydroxynitriles using HCN. • Outline the nucleophilic addition mechanism for the reaction with KCN followed by dilute acid (AQA)/water (OCR), HCN in presence of KCN (Pearson Edexcel).	**Lesson outcomes how successful learning is demonstrated** • Write correct reaction mechanisms, using "curly arrows" for a range of nucleophilic addition reactions where the nucleophiles are either: i. Hydride ions (sourced from either $NaBH_4$ or $LiBH_4$/dry ether) ii. Cyanide ions (sourced from HCN/KCN in acidic conditions). Mechanisms should include curly arrows and relevant lone pairs of electrons dipoles. • In NA reactions involving carbonyl compounds, identify, where appropriate, the presence of chiral centres and explain the presence of optical isomers. • Correctly explain the formation of optical isomers in nucleophilic additions reactions of carbonyl compounds.

• Explain why nucleophilic addition reactions of KCN, followed by dilute acid, can produce a mixture of products. • Use curly arrows, relevant lone pairs, dipoles and evidence of optical activity to show the mechanisms.	

Barriers to learning

Students will need previous knowledge relating to electronegativity, bond polarity, covalent bonding and drawing displayed organic structures. They will need to be familiar with the functional groups aldehyde and ketone and the concept of chirality.

Equipment / resources required

- Name labels (one per student)
- Black felt tipped pens
- PowerPoint
- Balloons
- Student summary sheets
- Sheets of A3 paper/flip chart paper
- Sample exam question and mark scheme

Drama kit

- Multi coloured felt tipped pens
- Cards with names of reagents on them (bromoethane, 1-bromopropane, bromomethane)
- Cards with names of nucleophiles on them H^-, CN^-
- Rulers with Velcro on
- Cards with + or – on them
- Small fabric balls
- Cards with $\delta+$, δ^- on
- Velcro
- String
- Pipe cleaners

• Party poppers • Multicoloured stickers • Juggling balls • Blutac • Straws • Sticky butterflies • Flipping frogs • Foam paintbrushes • Goggle glasses • Large multi coloured springs • Multi coloured balloons • Large red cardboard arrows • String • Coloureds felt tipped pens
Health and safety issues Ensure working area for drama is clear of obstacles

Lesson content, drama group, Phase 3

Planned timing (mins)	Researcher activity	Student activity
5	Introduce self and purpose of this lesson.	Students write name badges.
15	**Recap on existing knowledge** Use Q&A to recap • Definition of a nucleophile - A species (ion or molecule) with a lone pair of electrons that is available to form a coordinate bond (covalent bond in which both electrons come from one species). Nucleophiles are attracted to regions of positive charge (areas of electron deficiency).	• Students answer questions and direct CAO on what to write on the board.

	• Emphasis of the key features of curly arrows (representing the movement of electrons from areas of high electron density to areas of low electron density. Double headed arrow indicates the movement of two electrons that can be the movement of a lone pair of electrons to make a new covalent bond or the breaking of a covalent bond. • What a reaction mechanism is (a means of showing a series of movements of electrons allowing a logical reaction pathway to be visualised). • What the structure of the aldehyde and ketone functional groups are (emphasise, both have carbonyl groups).	
	<u>Introduction of new material</u> • Introduce today's nucleophiles: H^- and CN^-.	

25	• Draw ethanal (CH_3CHO) as the starting molecule on the board and using H^- as the nucleophile via Q&A go step by step through the NA mechanism. **Key questions** • Where will the nucleophile attack? • Why here? • Draw relevant polarities on the ethanal and draw curly arrow to show attack of the nucleophile. • What will happen as a result of this attack? • Why does the resulting intermediate have a negative charge? • In acidic solution what will happen now? Repeat using butan-2-one ($C_2H_5COCH_3$) and CN^- using the questions above. Before the final question Introduce the idea of a chiral centre. Use balloons to demonstrate front and back attack by the nucleophile to produce a chiral centre. **Demonstration of learning** • Introduce the task. • Students are to write their own simulation-role-pay to represent the reaction/s they have been allocated using the props provided.	• Students work in groups of 4 to produce their simulation-role-play given their own set of reaction conditions.

	• Working in groups of 4/5 students are given 10 minutes to practice/refine their simulation-role-play. They also write the reaction mechanism and which props they have used to represent key aspects of the mechanism they have been allocated or their reaction on the worksheets provided. • Each group also writes down their reaction mechanism on a sheet of A3 paper/flip chart paper noting the nucleophile and the leaving group.	
	• Students act out their simulation-role-play to the rest of the class. • Observers write down the mechanism for the simulation-role-play reactions they have not acted out themselves.	• Students enact /observe and write the mechanisms into their worksheets.
10	• Students complete common exam style question and check answers against the mark scheme provided.	• Students work individually to answer questions then self-mark.
5 If enough time, otherwise leave information with host teacher	• Explain the purpose of the research. • Explain that I will be leaving examination questions for completion in approx. 2 weeks.	

A.2.2 Lesson plan for examination-style question group, Phase 3

Lesson plan, examination-style question group, Phase 3	
Subject and title of scheme	Nucleophilic addition for AQA and OCR A and Pearson Edexcel
Learning objectives • Outline the nucleophilic addition mechanism for reduction reactions with $NaBH_4$ (AQA and OCR A) $LiAlH_4$ in dry ether (Pearson Edexcel) (the nucleophile should be shown as H^-). • Write overall equations for the formation of hydroxynitriles using HCN. • Outline the nucleophilic addition mechanism for the reaction with KCN followed by dilute acid (AQA)/water (OCR), HCN in presence of KCN (Pearson Edexcel). • Explain why nucleophilic addition reactions of KCN, followed by dilute acid, can produce a mixture of products. • Use curly arrows, relevant lone pairs, dipoles and evidence of optical activity to show the mechanisms.	**Lesson outcomes how successful learning is demonstrated** • Write correct reaction mechanisms, using "curly arrows", lone pairs of electrons and dipoles, for a range of nucleophilic addition reactions where the nucleophiles are either: i. Hydride ions (sourced from either $NaBH_4$ or $LiBH_4$/dry ether) ii. Cyanide ions (sourced from HCN/KCN in acidic conditions). • In nucleophilic addition reactions involving carbonyl compounds, identify, where appropriate, the presence of chiral centres and explain the presence of optical isomers. • Correctly explain the formation of optical isomers in nucleophilic additions reactions of carbonyl compounds.

<u>Barriers to learning</u> Students will need previous knowledge relating to electronegativity, bond polarity, covalent bonding and drawing displayed organic structures. They will need to be familiar with the functional groups aldehyde and ketone and the concept of chirality.
<u>Equipment / resources required</u> • Name labels (one per student) • Black felt tipped pens • PowerPoint • Balloons • Student summary sheets • Exam questions and mark scheme • Common exam question and mark scheme
<u>Health and safety issue</u> None

<u>Lesson content, examination-style question group, Phase 3</u>

Planned timing (mins)	Researcher activity	Student activity
5	Introduce self and purpose of this lesson.	Students write name badges.
15	**<u>Recap on existing knowledge</u>** Use Q&A to recap • Definition of a nucleophile: a species (ion or molecule) with a lone pair of electrons that is available to form a coordinate bond (covalent bond in which both electrons come from one species). Nucleophiles are attracted to regions of positive charge (areas of electron deficiency).	• Students answer questions and direct CAO on what to write on the board.

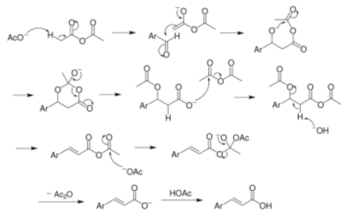
	• Emphasis of the key features of curly arrows (representing the movement of electrons from areas of high electron density to areas of low electron density. Double headed arrow indicates the movement of two electrons that can be the movement of a lone pair of electrons to make a new covalent bond or the breaking of a covalent bond. • What a reaction mechanism is (a means of showing a series of movements of electrons allowing a logical reaction pathway to be visualised). • What the structure of the aldehyde and ketone functional groups are (emphasise, both have carbonyl groups).	
	Introduction of new material • Introduce todays nucleophiles H^- and CN^-. • Draw ethanal (CH_3CHO) as the starting molecule on the board and using H^- as the nucleophile via Q&A go step by step through the NA mechanism.	

	Key questions • Where will the nucleophile attack? • Why here? • Draw relevant polarities on the ethanal and draw curly arrow to show attack of the nucleophile. • What will happen as a result of this attack? • Why does the resulting intermediate have a negative charge? • In acidic solution what will happen now? Repeat using butan-2-one ($C_2H_5COCH_3$ and CN^- using the questions above. Before the final question Introduce the idea of a chiral centre. Use balloons to demonstrate front and back attack by the nucleophile to produce a chiral centre.	• At each stage of the reaction students answer the questions to complete the reaction mechanism in their notebooks. • At each stage of the reaction students answer the questions to complete the reaction mechanism in their notebooks. For the final step draw both enantiomers in their book with 3 D representations before protonation.
25	**Demonstration of learning** • Introduce the task.	• Students work individually to answer questions, may talk with

	• Explain students are to work on exam type questions from text books/examination papers. Questions to be provided pre-printed. • Students then self-mark using the mark scheme provided.	other students in their group or ask for assistance from teacher. • Students mark work, asking for assistance from other students and/or researcher if needed.
10	Students complete common exam style question and check answers against the mark scheme provided.	Students work individually to answer questions then self-mark.
5 If enough time, otherwise leave information with host teacher	• Explain the purpose of the research. • Explain that I will be leaving examination questions for completion in approx. 2 weeks.	

A.2.3 PowerPoint slides for both drama and examination-style question group lessons, Phase 3

Organic reaction mechanisms
Nucleophilic substitution



Slide 1

Outcomes for this lesson

- To be able to identify aldehydes and ketones (both types of carbonyl compounds)
- To identify a nucleophile (revision)
- To successfully write reaction mechanisms, using "curly arrows" for a range of nucleophilic addition reactions

Slide 2

Carbonyl compounds

- Carbonyl group is a functional group composed of a carbon atom double-bonded to an oxygen atom: C=O

aldehyde ketone

Slide 3

H:⁻
a hydride ion

Obtained from $NaBH_4$ or $LiAlH_4$

:C≡N
A cyanide ion

Obtained from KCN / H^+

These are both nucleophiles, with a lone pair of electrons to attack at areas of electron deficiency, donating the lone pair to produce a new single covalent (dative bond)

Slide 4

reaction mechanism (revision from AS work)

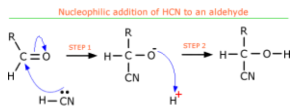
A means of showing a series of movements of electrons allowing a logical reaction pathway to be visualised.

Curly arrows representing the movement of electrons from areas of high electron density to areas of low electron density. Double headed arrow indicates the movement of two electrons.

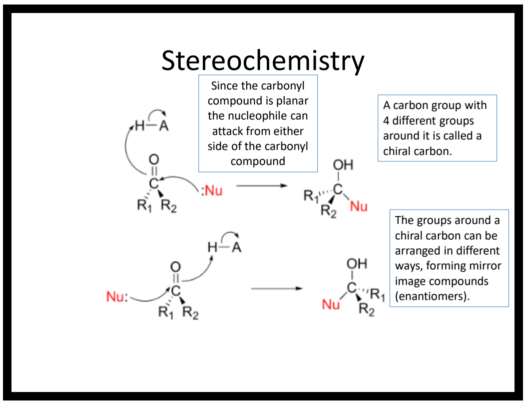
Slide 5

Nucleophilic addition

- Attack by the nucleophile results new Nu-C bond.
- One bond between C-O results in O^-
- O^- forms new bond with H^+ or abstracts H^+ from water. (don't worry about the last bit today)



Slide 6


Stereochemistry
Since the carbonyl compound is planar the nucleophile can attack from either side of the carbonyl compound
A carbon group with 4 different groups around it is called a chiral carbon.
The groups around a chiral carbon can be arranged in different ways, forming mirror image compounds (enantiomers).
H–A
O
C
R1 R2
:Nu
OH
C
R1
R2
Nu
H–A
O
C
Nu:
R1 R2
OH
C
R1
Nu
R2

Slide 7

A.2.4 Drama lesson worksheet, Phase 3

Your task is to design a dramatic representation for the reaction below that your group have been allocated

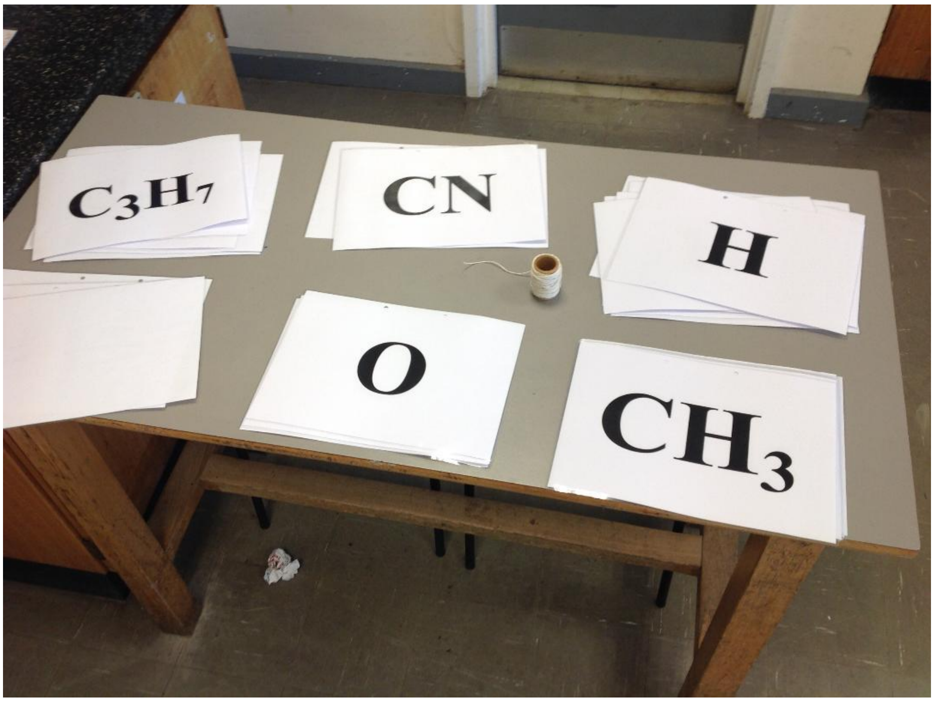
a. Butanal with acidified potassium cyanide
b. Pentan-2-one with sodium tetrahydroborate(III) (sodium borohydride, $NaBH_4$)
c. Butanal with lithium tetrahydrioaluminate(III) (also known as lithium aluminium hydride, $LiAlH_4$)

First of all, draw the reaction mechanism for the reaction you have been allocated in the box below

Now using the kit provided produce a dramatic representation of your reaction to share with the rest of the group. Record how you represented the following in your drama.

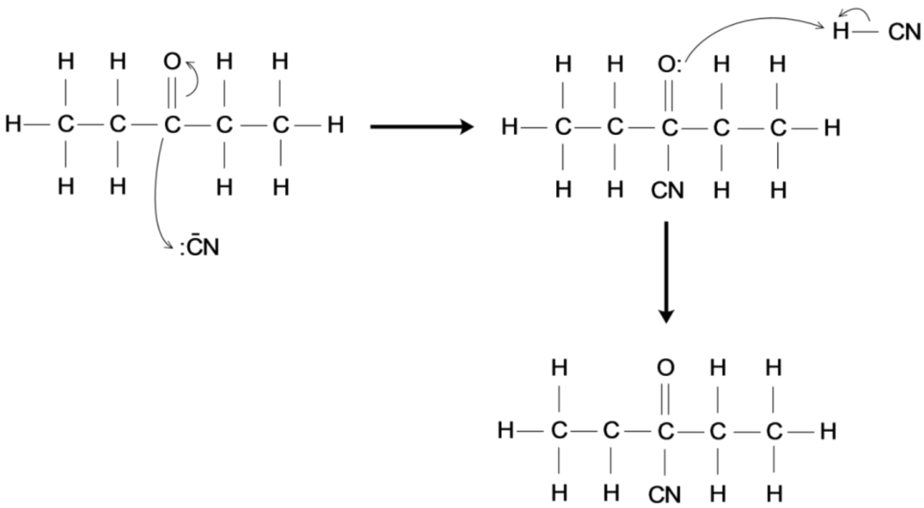
Key idea	**How we represented this**
Representation of the nucleophile	
Polarities of the C and O in the carbonyl group within the larger molecule	
Attack of the nucleophile at the δ+ carbon and formation of a new dative covalent bond	
Breaking of one of the carbon/oxygen bonds and subsequent charge distribution	
Attack of the oxygen lone pair of electrons on acidic hydrogen to give final product	
Showing how enantiomers form (if applicable)	

A.2.5 Photographs of props available for students to use when performing scripts, Phase 3


C_3H_7
CN
H
O
CH_3

A.2.6 Questions for the examination-style question group lesson, Phase 3

1. Below is a mechanism for the reaction between a cyanide ion and a ketone. The mechanism has 6 errors in it. **Circle the errors.**



6 marks

2. For the compounds below draw out the mechanism of the reaction with hydrogen cyanide in full.

   i. butanal

7 marks

ii. pentan-2-one

7 marks

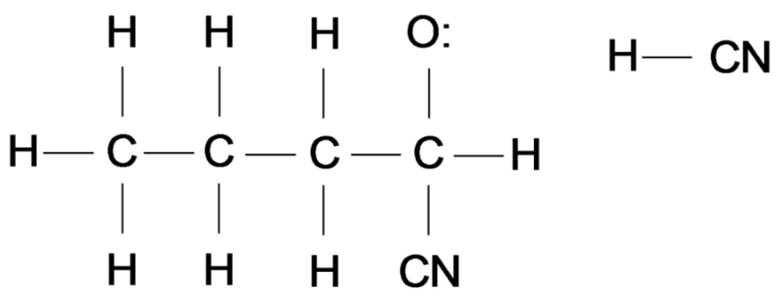
iii. 2-methylhexan-5-one

7 marks

iv. 3-methyl,4-ethyloctanal

4 marks

3. Cyanide ions can come from hydrogen cyanide, which will also be present in the reactions above. On the diagram below show the mechanism.



2 marks

4.i. Draw the structures of the two products formed when hexan-2-one is treated with acidified potassium cyanide solution.

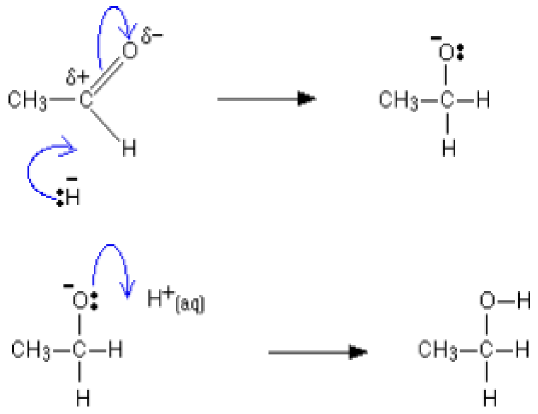
2 marks

ii. Explain why these two different compounds form.

3 marks

5. One way of using $NaBH_4$ to reduce the carbon-oxygen double bond in an aldehyde or ketone is tc react the carbonyl compound with a solution of $NaBH_4$ in water to which a little sodium hydroxic has been added. Following the initial reaction, the reaction is completed by acidifying the solutio

Simplifying things so that the BH_4^- ion is considered as a source of hydride ions, H^-, the mechanis for the reduction of an aldehyde like ethanal is:



a) Describe and explain what is happening during these reactions.

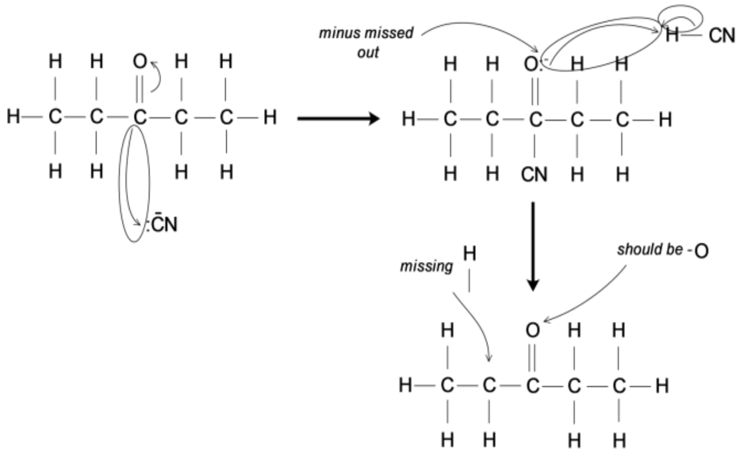
5 marks

b) What type of alcohol is produced every time a ketone is reduced using $NaBH_4$?

1 mark

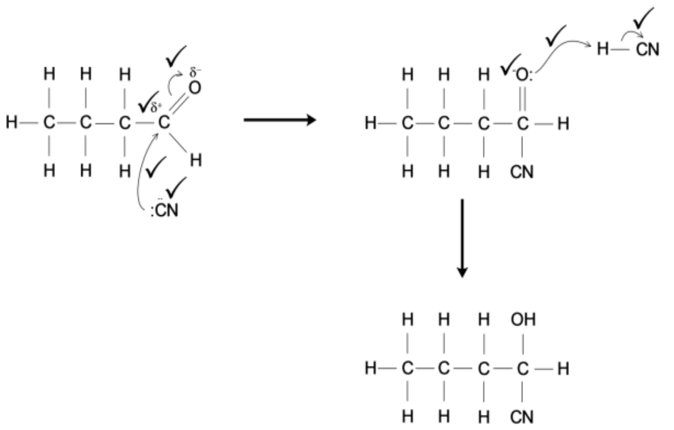
A.2.7 Answers to questions used in examination-style question group lesson, Phase 3

1



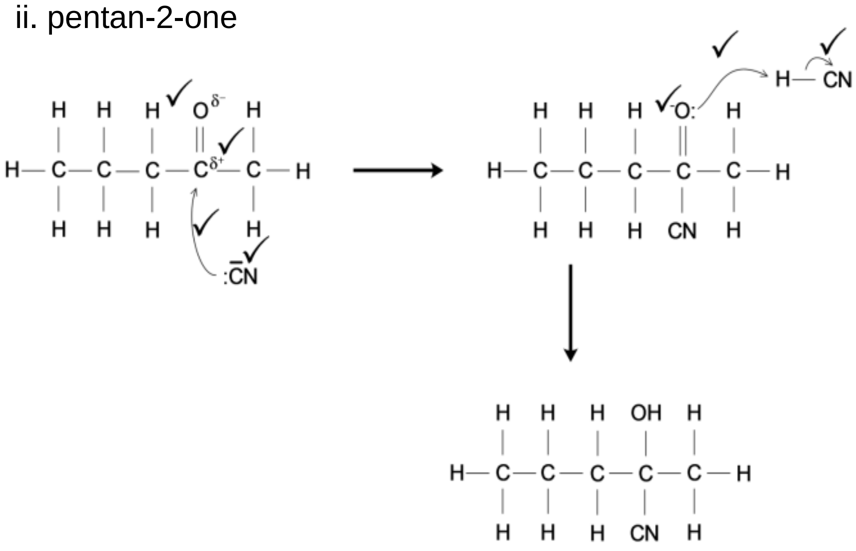
1 mark for each correct error

i. butanal



1 mark for each correct tick

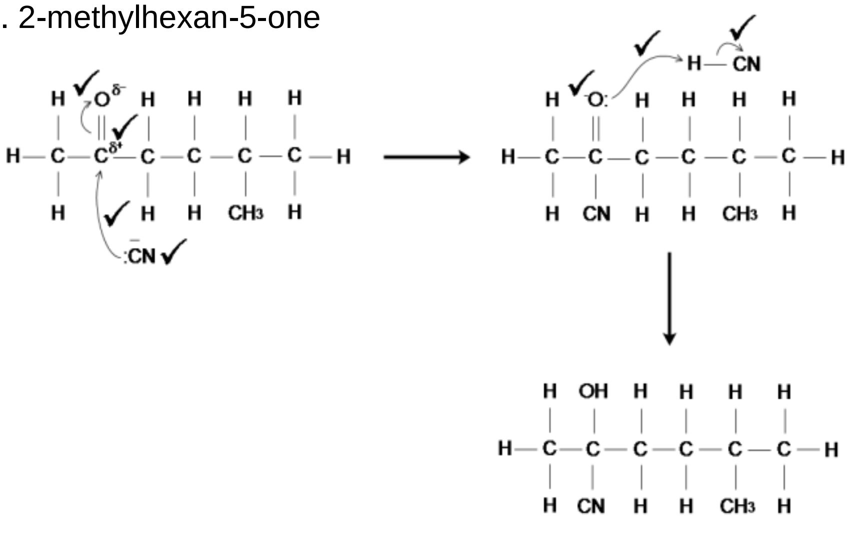
ii. pentan-2-one



2-Hydroxy-2-methylpentanenitrile

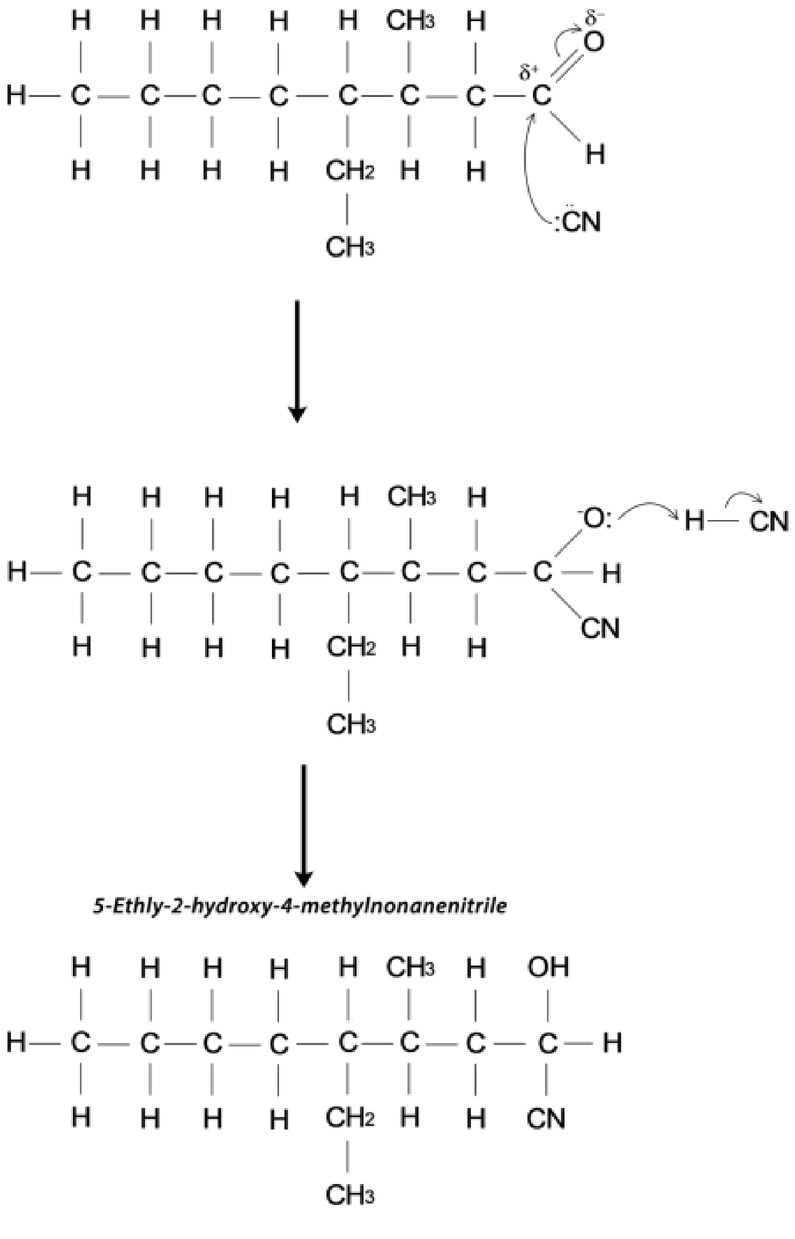
1 mark for each correct tick

iii. 2-methylhexan-5-one



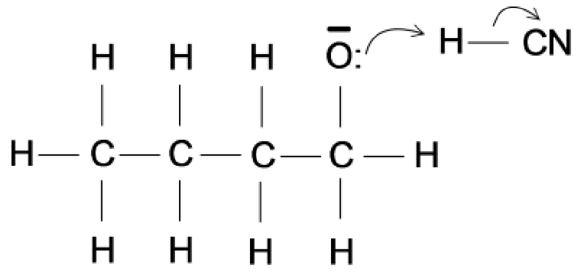
2 - hydroxy, 2-5 - dimethylhexannitrile

iv. 3-methyl,4-ethyloctanal



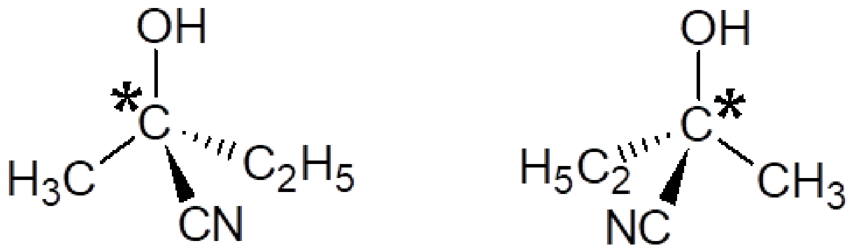
1 mark for each correct tick

3.



1 mark for each correct tick identified

4.i)



1 mark for each correct product

i. The carbonyl group is trigonal planar (1 mark) and therefore attack by the nucleophile can be from either side (1 mark), so forming two different chiral compounds (1 mark)

5.a

The lone pair of electrons on the nucleophile	1 mark
attack at the electron deficient carbon of the carbonyl group	1 mark
The lone pair of electrons forms a new dative covalent bond	1 mark
One of the carbon/oxygen bonds breaks, resulting in a negative charge on the electronegative oxygen	1 mark
The lone pair of electrons on the oxygen forms a new dative covalent bond with the proton	1 mark

b. primary alcohol (1 mark)

A.2.8 Examination question used for both drama and examination-style question group lessons, Phase 3

a.

i. Write out the *mechanism* for propanal reacting with acidified potassium cyanide solution. Include full structural formulae.

6 marks

ii. What type of compound is formed?

1 mark

b.

i. Write the mechanism for when propanal is reaction with sodium borohydride then dilute acid added.

6 marks

ii. What type of compound is formed?

1 mark

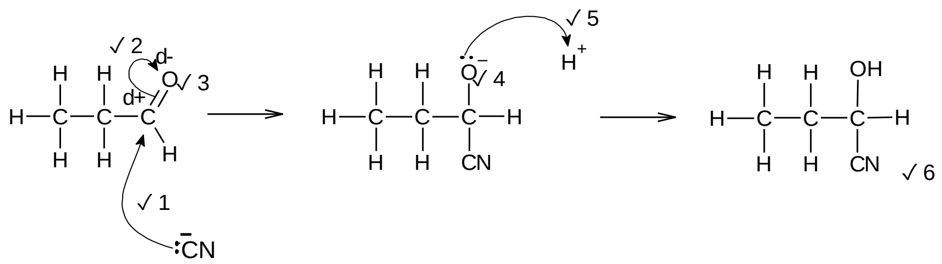
c. Describe why there are two different products in reaction the reaction in part a above, but only one product in the reaction in part b above.

5 marks

A.2.9 Answers to examination questions used for both drama and examination-style question group lessons, Phase 3

a.

i. Write out the *mechanism* for propanal reacting with acidified potassium cyanide solution. Include full structural formulae.



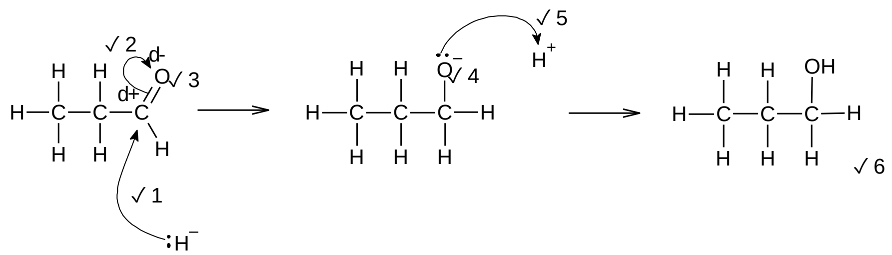
6 marks

ii. What type of compound is formed?

hydroxynitrile (cyanohydrin) 1mark

b.

i. Write the mechanism for when propanal is reacted with sodium borohydride then dilute acid added.



6 marks

ii. What type of compound is formed?

primary alcohol 1 mark

c. Describe why there are two different products in reaction the reaction in part a above, but only one product in the reaction in part b above.

Aldehyde group is planar	1 mark
Attack by the nucleophile can be from either side (back or front)	1 mark
Because the product in reaction a results in a chiral carbon with (4 **different** groups attached)	1 mark
Two different enantiomers (non-superimposable isomers) can form	1 mark
The product in reaction b does not produce enantiomers, i.e. only one product forms	1 mark

Appendix B
Post-intervention Assessment Items and Mark Schemes

B.1 Post-intervention assessment items, Phases 1 and 2

1. A student read the following passage on the Internet.

Haloalkanes contain a polar covalent bond. The carbon atom of the polar covalent bond can be attacked by nucleophiles. Nucleophilic attack enables haloalkanes to undergo substitution reactions.

A nucleophilic substitution reaction occurs when a haloalkane undergoes hydrolysis; the rate of hydrolysis of the haloalkane is influenced by the carbon—halogen bond enthalpy.

(a) Explain the meaning of each of the following terms in the information given above.

(i) nucleophile

____

____

(1 mark)

(ii) substitution, as applied to nucleophilic substitution in a haloalkane

____

____

(1 mark)

(b) Outline a mechanism for the nucleophilic substitution reaction in which 2-bromopropane ($CH_3CHBrCH_3$) reacts with potassium hydroxide to form propan-2-ol.

(2 marks)

2. Butan-l-ol can be prepared by the alkaline hydrolysis of I-iodobutane

$CH_3CH_2CH_2CH_2I + OH^- \longrightarrow CH_3CH_2CH_2CH_20H + I$

The reaction mixture is gently heated for 20 minutes.

(i) The curly arrow model Is used in reaction mechanisms to show the movement of electron pairs.

Use the curly arrow model to outline the mechanism for the alkaline hydrolysis of 1-iodobutane.

In your answer, include the name of the mechanism, the type of bond fission and relevant dipoles.

Name of mechanism

____

(4 marks)

3. The reaction of butane-I,4-dioI with butanedioic acid produces the polymer PBS used in biodegradable packaging and disposable cutlery.

Butanedioic acid is produced in the following process

i. Aqueous sodium hydroxide reacts with 1,4-dibromobutane to make

butane-1,4-diol

ii. Butane-1,4-diol is then oxidised to butanedioic acid.

Name and outline a mechanism for the following reaction that occurs in reaction i) (the equation is given below)

$$BrCH_2CH_2CH_2CH_2Br + 2NaOH \longrightarrow HOCH_2CH_2CH_2CH_2OH + 2NaBr$$

Name of reaction

____

Mechanism:

(3 marks)

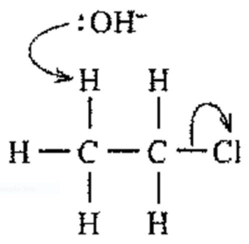
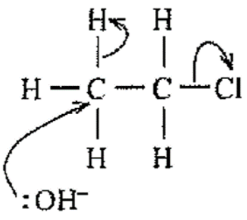
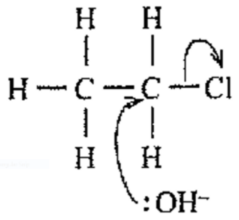
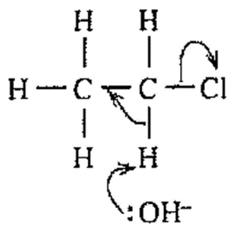
4. Chloroethane reacts with aqueous potassium hydroxide solution producing ethanol as the organic product.

(a) The hydroxide ion is acting as, place a tick in the box next to the correct answer

A	an electrophile	☐
B	a nucleophile	☐
C	an oxidising agent	☐
D	a reducing agent	☐

(1 mark)

(b) Which of the following shows the correct electron-pair movements in this reaction? Place a tick in the box to the left of letter corresponding to the correct answer.

	A	
	B	
	C	
	D	

(2 marks)

5. This question is about ethanethiol, CH_3CH_2SH. Thiols are like alcohols, but the oxygen atom has been replaced by a sulfur atom. They react in a similar way to alcohols.

Ethanol can be made from bromoethane by reaction with aqueous potassium hydroxide, KOH (aq), under suitable conditions.

(i) Write the equation for this reaction. State symbols are not required.

(1mark)

(ii) State the type and mechanism of this reaction.

____

(2 marks)

(iii) Suggest the formula of a suitable chemical to make ethanethiol from bromoethane.

____

(1 mark)

B.1.1 Mark scheme and coding for post-intervention assessment items, Phases 1 and 2

All text in **bold** in the mark scheme indicates a correct answer. The follow is a key to the structure of the table:

Column 1: Question number for assessment item.

Column 2: Mark number awarded using the examination board mark scheme, coupled with a brief description of what that mark relates to.

Column 3: Coding options for the examination board mark.

Column 4: Extra comments to the marker relating to columns 1 and 2

Column 5: Fine-grain mark scheme number

Column 6: Combinations of codes from column 3 deemed to be mark-worthy using the fine-grain mark scheme

1	2	3	4	5	6
Q. No.	**Question ref. and brief description**	**Coding options**	**Extra comments for mark scheme**	**Fine-grain mark**	**For all, code:** **0 for no mark** **1 for mark awarded**
Mark 1	1 ai Lone pair identification	0 no answer **1 identifies lone pair of electrons present** 2 no reference to lone pair of electrons present 3 other incorrect answer		1	Code 1 for mark
	Attack of lone pair	0 no answer at all **1 identifies attack at area of electron deficiency/positive charge (not nucleus)** 2 an answer but no reference to attack at area of electron deficiency 3 other incorrect answer e.g. attracted to nucleus/positive ion		2	Code 1 for mark
	Formation of covalent bond	0 no answer at all **1 identifies formation of new (dative) covalent bond** 2 an answer but no reference to formation of new dative covalent bond 3 other incorrect answer		3	Code 1 for mark

1	2	3	4	5	6
Q. No.	**Question ref. and brief description**	**Coding options**	**Extra comments for mark scheme**	**Fine-grain mark**	**For all, code: 0 for no mark 1 for mark awarded**
	Mark 1 awarded?	0 no 1 yes	All **three** points above needed to gain the mark		
Mark 2	1aii	0 no answer **1 Replacement of the halogen by a nucleophile** 2 replacement/swapping only 3 incorrect answer	NOT substituted (given in question)	4	Code 1 for mark
	Mark 2 awarded?	0 no 1 yes			
Mark 3	1b Representation of nucleophile	0 no nucleophile drawn **1Correct representation of $\ddot{O}H^-$ (including charge and lone pair) accept $K^+\ddot{O}H^-$** 2 OH^- (correct formula and charge no lone pair) 3 $\ddot{O}H$ (OH with lone pair but no charge) 4 OH with no charge and no lone pair **5 $K\ddot{O}H$ with lone pair on O** 6 none of the above	Need to recognise **$\ddot{O}H^-$** as the nucleophile i.e. **$\ddot{O}H^-$ $K^+\ddot{O}H^-$**or **$K\ddot{O}H$** (codes 1or5) 6. incorrect answers could imply KOH being covalently bonded e.g. $K\text{-}OH^-$, $K\text{-}\ddot{O}H$, K-OH Lone pair on K or H incorrect	5	Codes 1, 2,3,4,5 for mark No mark awarded of KOH implied to be covalently bonded

1	2	3	4	5	6
Q. No.	**Question ref. and brief description**	**Coding options**	**Extra comments for mark scheme**	**Fine-grain mark**	**For all, code:** **0 for no mark** **1 for mark awarded**
	Identification of source and sink for attack To see whether they identify lone pair and δ^+	0 no answer **1 correct source and sink (lone pair and δ^+)** 2 correct source and sink (lone pair and δ^+) but lone pair not drawn (source from position where lone pair would be expected) 3 correct source (lone pair) and incorrect sink 4 incorrect source and correct sink δ^+ 5 incorrect source and incorrect sink 6 other e.g. vague, might be correct but not clear enough	No need for bond polarity to be included for this coding Should be indicating movement from lone pair of electrons to δ^+ carbon. Allow 1 even if lone pair is not in correct position in the nucleophile or incorrect nucleophile	6	Codes 1, 2 or 6 to gain mark

1	2	3	4	5	6
Q. No.	**Question ref. and brief description**	**Coding options**	**Extra comments for mark scheme**	**Fine-grain mark**	**For all, code: 0 for no mark 1 for mark awarded**
	Direction and position of attack arrow 1	0 no answer 1 not correct answer above **2 arrow moving from source to sink (correct distance from both)** 3 arrow moving from sink to source 4 correct direction but incorrect in other ways e.g. distances from source sink incorrect 5 other	Contingent on getting last section correct	7	Contingent on getting code 1, 2 or 6 above. Coding 2 or 4 gets mark
	Mark 3 awarded?	0 mark not awarded 1 mark awarded	Correct nucleophile, source/sink, arrow 1 direction and positioning **all** needed for mark		
Mark 4	Arrow 2 movement/ identification of source and sink	0 no answer **1 arrow from C-Br to Br** 2 arrow from C to Br 3 arrow from Br to C-Br 4 arrow from Br to C 5 other		8	Coding 1, 5 allowed for mark
	Position of arrow 2	0 no answer	Only code 2 if code 1 awarded above	9	Codes 2,3,4,5 gain mark.

1	2	3	4	5	6
Q. No.	**Question ref. and brief description**	**Coding options**	**Extra comments for mark scheme**	**Fine-grain mark**	**For all, code:** **0 for no mark** **1 for mark awarded**
		1 incorrect answer above (2-5) **2 arrow close enough to source and sink** 3 arrow close to source but too far from sink 4 arrow too far from source but close to sink 5 arrow too far from source and sink 6 other	 C – Br ✓(ideal)  C – Br ✓ (limit of precision for the mark)  C – Br x (too imprecise at both ends)		Contingent on gaining mark 8 above, but may be quite imprecise
	Mark 4 awarded?	0 mark not awarded 1 mark awarded	Correct position *and* direction for arrow 2 needed for mark		
Mark 5	2i C-I bond polarity	0 no attempt at identifying C-I bond polarity **1 correct labelling of C-I bond polarity** 2 incorrect labelling of C-I bond polarity 3 other e.g. polarity on incorrect bond	$C^{\delta+}$-$I^{\delta-}$	10	Code 1 gains mark
	Mark 5 awarded?	0 no 1 yes			

1	2	3	4	5	6
Q. No.	**Question ref. and brief description**	**Coding options**	**Extra comments for mark scheme**	**Fine-grain mark**	**For all, code:** **0 for no mark** **1 for mark awarded**
Mark 6	Representation of nucleophile	0 no nucleophile drawn **1Correct representation of $\ddot{O}H^-$ (including charge and lone pair) accept $K^+\ddot{O}H^-$** 2 OH^- (correct formula and charge no lone pair) 3 ÖH (OH with lone pair but no charge) 4 OH with no charge and no lone pair **5 KÖH with lone pair on O** 6 none of the above	Need to recognise **$\ddot{O}H^-$** as the nucleophile i.e. **$\ddot{O}H^-$ $K^+\ddot{O}H^-$**or **KÖH** (codes 1or5) 6. incorrect answers could imply KOH is covalently bonded e.g. K-OH^-, K-ÖH, K-OH Lone pair on K or H incorrect	11	Codes 1, 2,3,4,5 for mark No mark awarded of KOH implied to be covalently bonded
	Are source and sink identified?	0 no answer **1 correct source (lone pair on OH^- and sink δ^+ C** 2 correct source and sink but lone pair not identified 3 correct source and sink but δ^+ not identified 4 correct source, incorrect sink	Need lone pair to contribute to obtaining mark 6 No need for δ^+ to be written on script	12	Code 1,2,3 or 7 to gain mark

1	2	3	4	5	6
Q. No.	**Question ref. and brief description**	**Coding options**	**Extra comments for mark scheme**	**Fine-grain mark**	**For all, code:** **0 for no mark** **1 for mark awarded**
		5 incorrect source, correct sink 6 incorrect source, incorrect sink 7 other e.g. too vague – ***possibly*** correct source and sink			
	Position of attack arrow (arrow 1)	0 no answer **1 Correct positioning of arrow** 2 incorrect positioning of arrow (too far from correct sink and/or source or both) 3 other e.g. half headed arrow		13	Could be quite imprecise as long as it is clearly the correct source and sink Half-headed arrow accepted No need for lone pair of electrons to be drawn on, but implied
	Mark 6 awarded?	0 no 1 yes	Source, sink and arrow position **all** need to be correct for the mark.		

1	2	3	4	5	6
Q. No.	**Question ref. and brief description**	**Coding options**	**Extra comments for mark scheme**	**Fine-grain mark**	**For all, code:** **0 for no mark** **1 for mark awarded**
Mark 7	Arrow 2 (from C-I bond to create leaving group	0 no answer **1 arrow moving from C-I bond to I** 2 arrow moving from C-I bond (too far away) to I 3 arrow moving from C-I bond to I (too far away) 4 arrow moving in wrong direction 5 other e.g. half headed arrow	Only code 2 if code 1 awarded above  C – I✓(ideal)  C – I ✓ (limit of precision for the mark)  C – I x (too imprecise at both ends)	14	1,2 or 3 gains mark allow half arrows
	Mark 7 awarded?	0 no 1 yes			
Mark 8		0 no answer 1 nucleophilic in answer 2 substitution in answer **3 nucleophilic substitution** 3 other		15	Code 3 for mark
	Mark 8 awarded?	0 no 1 yes			

1	2	3	4	5	6
Q. No.	**Question ref. and brief description**	**Coding options**	**Extra comments for mark scheme**	**Fine-grain mark**	**For all, code: 0 for no mark 1 for mark awarded**
Mark 9	Q4	0 no answer 1 nucleophilic in answer 2 substitution in answer **3 nucleophilic substitution** 4 other		16	Code 3 for mark
	Mark 9 awarded?	0 no 1 yes			
Mark 10	Number of points of attack	0 no answer **1 attack at both ends of the molecule** 2 attack at only one end of the molecule 3 other	No need for accurate positioning of attack, this is assessing whether candidates know attack is x2 Attack at both ends may be shown stepwise	17	1 gains mark No credit for attack at one end only
	Nucleophile	0 no nucleophile **1 correct nucleophile/s** 2 incorrect nucleophile/s 3 one correct and one incorrect nucleophile	Need to recognise $\ddot{O}H^-$ as nucleophile ***Correct:*** $\ddot{O}H^-$, $Na^+\ddot{O}H^-$ or $Na\ddot{O}H$ ***Incorrect:*** $Na\text{-}OH^-$, $Na\text{-}\ddot{O}H$, $Na\text{-}OH$ (implies covalent)	18	Code for 1 NB. this question only codes for correct or incorrect nucleophil e

1	2	3	4	5	6
Q. No.	**Question ref. and brief description**	**Coding options**	**Extra comments for mark scheme**	**Fine-grain mark**	**For all, code:** **0 for no mark** **1 for mark awarded**
			OH, without lone pair *or* without charge NaOH with lone pair on Na or H		
	Position of attack (i)	0 no answer **1 attack from lone pair of electrons on correct nucleophile (x1 or x2)** 2 attack from lone pair of electrons on incorrect nucleophile (x1 or x2) 3 attack from point where lone pair of electrons would be expected to be <u>but not drawn</u> (x1 or x2) 4 attack form position other than lone pair of electrons (x1 or x2) 5 Different answers for two different attacks 6 Other	X1 refers to attack at only one end of the molecule X2 refers to attack at both ends of the molecule This mark relates to attack by lone pair of electrons (even if not drawn, but attack is from point where lone pair would be)	19	Codes 1,2,3 gain mark

1	2	3	4	5	6
Q. No.	**Question ref. and brief description**	**Coding options**	**Extra comments for mark scheme**	**Fine-grain mark**	**For all, code:** **0 for no mark** **1 for mark awarded**
	Position of attack (ii)	0 no answer **1 correct source and sink X2** 2 correct source and sink X1 3 correct source/sink combination x1 ***and incorrect*** sink/source combination x1 4 incorrect source/sink combination x2 5 incorrect source sink combination x1 6 other	i.e. attack from lone pair to C (lone pair must be present and sink must not be wide of C Ignore any labelling (or lack of) of bond polarity for this coding, **location** of attack is what is being assessed here. Incorrect may be due to too far from source **or** sink	20	Codes 1 or 2 and imprecise arrows gain mark
	Mark 10 awarded?	0 no 1 yes	Must have all 4 points above correct		

1	2	3	4	5	6
Q. No.	**Question ref. and brief description**	**Coding options**	**Extra comments for mark scheme**	**Fine-grain mark**	**For all, code:** **0 for no mark** **1 for mark awarded**
Mark 11	C-Br polarity	0 no answer **1 correct labelling of C-Br bond polarity x2** 2 correct labelling of C-Br bond polarity x1 3 incorrect labelling of C-Br bond polarity x1 4 incorrect labelling of C-Br bond polarity x2 5 other e.g. delta signs on species other than those in the C-Br bond		21	Codes 1 or 2 gain mark
	Breaking of C-Br bond	0 no answer **1 arrows moving from C-Br bond to Br x2** 2 arrow/s moving from C-Br bond (too far away) to Br x1 or x2 3 arrow/s moving from C-Br bond to Br (too far away) x1 or x2 4 arrow/s moving from C to Br x1 or x2 5 arrow/s moving in wrong direction x1 or x2 6 other e.g. two different for x2	Must be **two** correct arrows to contribute to gaining mark 11	22	Codes 1, 2 or 3 gain mark i.e. correct source and sink (x1 orx2), but might be vague positioning of the arrow

1	2	3	4	5	6
Q. No.	**Question ref. and brief description**	**Coding options**	**Extra comments for mark scheme**	**Fine-grain mark**	**For all, code: 0 for no mark 1 for mark awarded**
	Mark 11 awarded?	0 no 1 yes	Need to be x2 of both parts above to gain mark		
Mark 12 Structure of product		0 no answer **1 diol structure correct** 2 only one OH group 3 other product		23	Code 1 gains mark
	Mark 12 awarded?	0 no 1 yes			
Mark 13	Q5a Multiple choice	0 no answer 1A **2 B** 3 C 4 D 5 other		24	Code 2 gains the mark
	Mark 13 awarded?	0 no 1 yes			
Mark 14	Q5b Multiple choice	0 no answer 1A 2 B **3 C** 4 D 5 other		25	Code 3 gains the mark
	Mark 14 awarded?	0 no 1 yes			

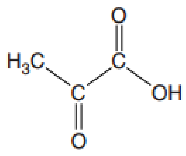
1	2	3	4	5	6
Q. No.	**Question ref. and brief description**	**Coding options**	**Extra comments for mark scheme**	**Fine-grain mark**	**For all, code: 0 for no mark 1 for mark awarded**
Mark 15	6i Formula equation for the reaction	0 no answer **1 reactants and products all correct** 2 correct products/incorrect reactants 3 correct reactants/incorrect products 4 incorrect product/s and incorrect reactant/s 5 other		26	Code 1 gains the mark
	Mark 15 awarded?	0 no 1 yes			
Mark 16	Q6ii Nucleophilic substitution	0 no answer 1 nucleophilic in answer 2 substitution in answer **3 nucleophilic substitution** 3 other		27	Code 3 gains the mark
	Mark 16 awarded?	0 no 1 yes			
Mark 17	Q6iii Alternative nucleophile	0 no answer **1 KSH/NaSH/SH_2**	High level question SH^-	28	Code 1 gains mark

1	2	3	4	5	6
Q. No.	**Question ref. and brief description**	**Coding options**	**Extra comments for mark scheme**	**Fine-grain mark**	**For all, code:** **0 for no mark** **1 for mark awarded**
		2 incorrect answer	counts as incorrect		
	Mark 17 awarded?	0 no 1 yes			

B.2 Post-intervention assessment items, Phase 3

OCR Q1 Jan 2013

1 Pyruvic acid, shown below, is an organic compound that has a smell similar to ethanoic acid. It is extremely soluble in water.



pyruvic acid

(c) Pyruvic acid can also be reduced by $NaBH_4$ to form $CH_3CH(OH)COOH$.

Outline the mechanism for this reduction.

Use curly arrows and show relevant dipoles.

[4]

AQA Chem 4 Q5 June 2014

2. The carbonyl compound CH_3CH_2CHO reacts very slowly with HCN

Name and outline a mechanism for the reaction of CH_3CH_2CHO with HCN

[5 marks]

Name of mechanism ....

Mechanism

5 (b) The reaction in Question **5 (a)** produces a pair of enantiomers.

5 (b) (i) Draw the structure of each enantiomer to show how they are related to each other.

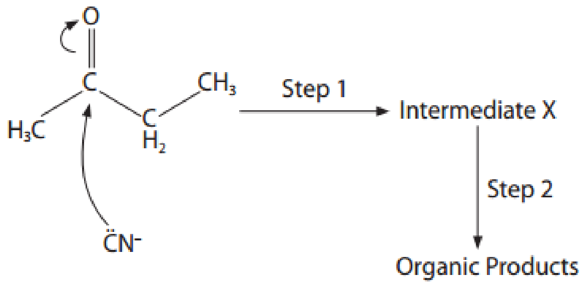
[2 marks]

(b)(ii) Explain how it is possible for these two products to form

[3 marks]

EDEXCEL Unit 4 Q12 June 2015

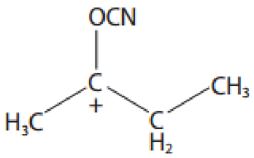
3. The diagram below shows part of the mechanism for the nucleophilic addition of hydrogen cyanide to butanone.



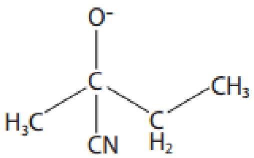
(a) The formula of the intermediate X is

(1)

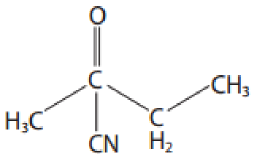
☒ **A**



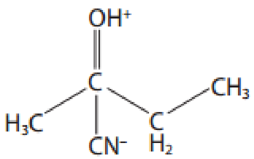
☒ **B**



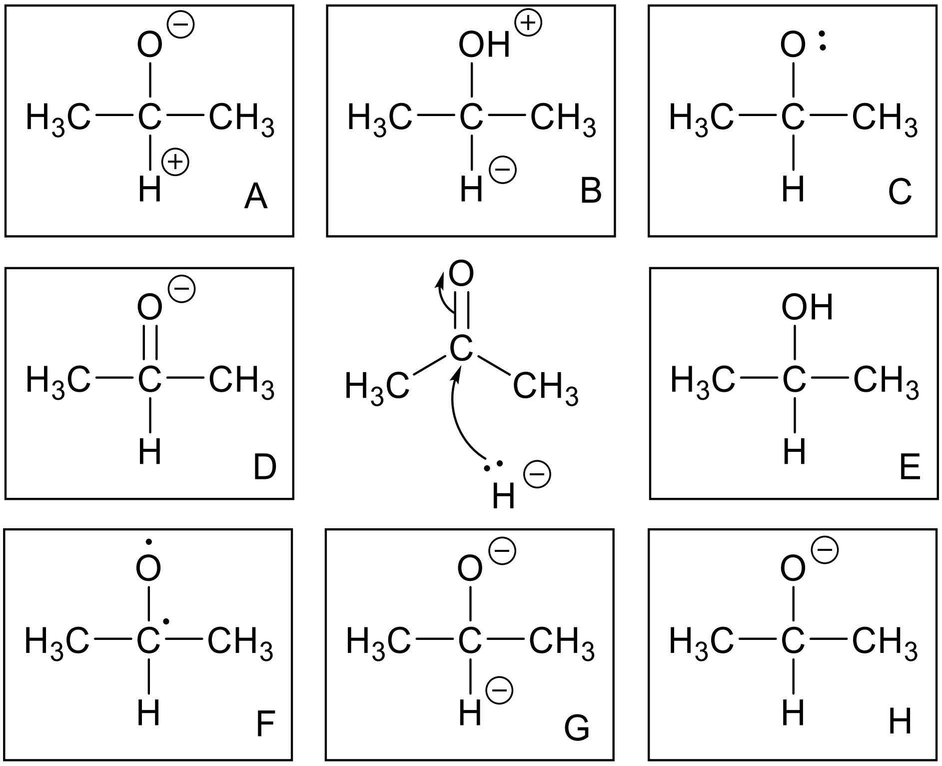
☒ **C**



☒ **D**



4. The central diagram below shows the initial stage of a reaction mechanism, surrounded by a selection of suggestions for the result of that reaction step labelled A-G). Identify which **ONE** diagram is correct (A, B, C, D, E, F, G **or** H) and write an answer explaining why you selected this diagram in the space provided.



The diagram I selected as the correct outcome is letter

I selected this diagram because:

……………………………………………………………………………………

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B.2.1 Mark scheme and coding for post-intervention assessment items, Phase 3

All text in **bold** in the mark scheme indicates a correct answer. The follow is a key to the structure of the table:

Column 1: Question number for assessment item.

Column 2: Mark number awarded using the examination board mark scheme, coupled with a brief description of what that mark relates to.

Column 3: Coding options for the examination board mark.

Column 4: Extra comments to the marker relating to columns 1 and 2

Column 5: Fine-grain mark scheme number

Column 6: Combinations of codes from column 3 deemed to be mark-worthy using the fine-grain mark scheme

1	2	3	4	5	6
Q. No.	**Mark**	**Coding options**	**Extra comments**	**Fine-grain mark**	**For all, code: 1 for mark, 0 for no mark**
1	Mark 1 Source	0 no answer **1 arrow *from* lone pair or minus sign on H^-** 2 attack from nucleophile from lone pair or –ve charge with lone pair or negative charge (where no attack is from) missing 3 attack from nucleophile, but which part unclear 4 other		1	Codes 1,2 gain mark
	Arrow 1 sink	0 no answer **1.Arrow to C in carbonyl group** *of the ketone* 2 Arrow to C in carbonyl of *carboxylic acid* group 3 other		2	Codes 1,2 gain mark

1	2	3	4	5	6
Q. No.	**Mark**	**Coding options**	**Extra comments**	**Fine-grain mark**	**For all, code: 1 for mark, 0 for no mark**
	Arrow 1 position	0 no answer **1 Arrow close enough to source and sink** 2 Arrow wide of correct source ***or*** sink 3 Arrow wide of correct source ***and*** sink 4 other e.g. incorrect source/sink combination		3	Codes 1,2,3 gain mark
	Mark 1 awarded?	0 no mark awarded **1 mark awarded**	**Must have all 3 points above correct to gain mark**		
	Mark 2 dipole	0. no answer **1.Correct dipole on carbonyl $C^{\delta+}$ $O^{\delta-}$** 2.Correct dipole on carboxylic acid carbonyl $C^{\delta+}$ $O^{\delta-}$ (only if this is position of attack for mark 1) 3. other e.g. incorrect dipole or incorrect bond		4	1, 2 gain mark
	Arrow 2 Source /sink	0 no answer **1.curly arrow from carbonyl**	Have the correct source and sink been identified	5	1,2,3,4 gain mark

1	2	3	4	5	6
Q. No.	**Mark**	**Coding options**	**Extra comments**	**Fine-grain mark**	**For all, code: 1 for mark, 0 for no mark**
		double bond to $O^{\delta-}$ 2.curly arrow from carbonyl double bond to O (no δ^-) 3.curly arrow from carboxylic acid carbonyl double bond to $O^{\delta-}$ 4.curly arrow from carboxylic carbonyl double bond to O (no δ^-) 5 other			
	Arrow 2 position	0 no answer **1 Arrow close enough to source and sink** 2 Arrow wide of correct source ***or*** sink 3 arrow wide of both correct source ***and*** correct sink 4 other	Position of arrow in relation to correct source and sink	6	1,2,3 gain mark
	Mark 2 awarded?	0 no mark 1 mark awarded			

1	2	3	4	5	6
Q. No.	**Mark**	**Coding options**	**Extra comments**	**Fine-grain mark**	**For all, code: 1 for mark, 0 for no mark**
	Mark 3 intermediate	0 no answer **1correct intermediate with –ve charge on O.** 2 'correct' intermediate if attack had taken place at the carboxylic acid with –ve charge on O 3 correct intermediate **no** –ve charge on O. 4 'correct' intermediate if attack had taken place at the carboxylic acid with **no** –ve charge on O 5 other	Lone pair on O^- in intermediate does not need to be shown.	7	Codes 1, 2,3,4 gain mark
	Mark 3 awarded?	0 no mark 1 mark awarded			

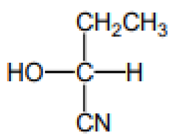
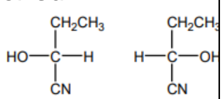
1	2	3	4	5	6
Q. No.	**Mark**	**Coding options**	**Extra comments**	**Fine-grain mark**	**For all, code: 1 for mark, 0 for no mark**
	Mark 4 Arrow 3 source and sink	0 no answer **1 Curly arrow from O^- of correct intermediate to H in H_2O or to H^+** **2 not needed as H^+ used instead of H_20 for arrow 3 above** 3Curly arrow from O^- of incorrect intermediate to H in H_2O or to H^+ 4 Curly arrow from O of correct intermediate (no –ve sign on O) to H in H_2O or to H^+ 5 Curly arrow from O of incorrect intermediate (no –ve sign on O) to H in H_2O or to H^+ 6 other	Identification of source and sink Arrow must start from –ve sign or lone pair on O^-	8	1,2,3,4,5 gain mark
	Arrow 3 position	0 no answer **1 Arrow close enough to correct source and sink** **2 not needed as H^+ used instead of H_20 for arrow 3 above** **3** Arrow wide of correct source ***or*** sink 4 arrow wide of both correct source ***and*** correct sink 5 other	Judgement based on either intermediate (from attack on either carbonyl)	9	1,2,3,4 gain mark

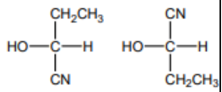
1	2	3	4	5	6
Q. No.	**Mark**	**Coding options**	**Extra comments**	**Fine-grain mark**	**For all, code: 1 for mark, 0 for no mark**
	Arrow 4 Source and sink	**0 no answer** **1 curly arrow from OH bond to the O in H_2O** 2 incorrect source ***or*** sink 3 incorrect source ***and*** sink 4 other	No need to show OH^- Allow mark for curly arrow from O^- to H^+	10	1,2 gain mark
	Arrow 4 position	**1 Arrow close enough to source and sink** 2 Arrow wide of correct source ***or*** sink 3 arrow wide of both correct source ***and*** correct sink 4 other	Other if arrow in wrong direction for example	11	1,2,3 gain mark
	Mark 4 awarded?	0 no mark 1 mark awarded			
2a	**Mark 5**	0 no answer **1 nucleophilic addition** 3 includes nucleophilic 4 includes addition 5 incorrect answer		12	1 gains mark
	Mark 5 awarded?	0 no mark 1 mark awarded			

1	2	3	4	5	6
Q. No.	**Mark**	**Coding options**	**Extra comments**	**Fine-grain mark**	**For all, code: 1 for mark, 0 for no mark**
2a	**Mark 6** Arrow 1 source	0 no answer **1 arrow *from* lone pair or minus sign in CN^-** 2 attack from nucleophile from lone pair or –ve charge with lone pair or negative charge (where no attack is from missing) 3 attack from nucleophile, but which part unclear 4 other	Identification of source only	13	1,2 gain mark
	Arrow 1 sink	0 no answer **1.Arrow to C in carbonyl group** 2 Arrow to another sink	Identification of sink only	14	1 gains mark
	Arrow 1 position	0 no answer **1 Arrow close enough to correct source and sink** 2 Arrow wide of correct source ***or*** sink 3 Arrow wide of correct source ***and*** sink 4 other	Location of arrow	15	1,2,3 gain mark
	Mark 6 awarded?	0 no mark 1 mark awarded			
	Mark 7	0 no answer		16	1,2 gain mark

1	2	3	4	5	6
Q. No.	**Mark**	**Coding options**	**Extra comments**	**Fine-grain mark**	**For all, code: 1 for mark, 0 for no mark**
	Arrow 2 source and sink	**1.curly arrow from carbonyl double bond to $O^{\delta-}$** 2.curly arrow from carbonyl double bond to O (no δ- present) 3 other e.g. incorrect polarity on O	Identification of correct source and sink		
	Arrow 2 position	0 no answer **1 Arrow close enough to correct source and sink** 2 Arrow wide of correct source ***or*** sink 3 arrow wide of both correct source ***and*** correct sink 4 other	Position of arrow in relation to correct source and sink	17	1,2,3 gain mark
	Mark 7 awarded?	0 no mark 1 mark awarded			
	Mark 8 intermediate	0 no answer **1 correct intermediate –ve charge shown** 2 correct intermediate –ve charge not shown 3 incorrect intermediate 4 other	Lone pair on O^- in intermediate does not need to be shown.	18	1,2 gain mark
	Mark 8 awarded?	0 no mark 1 mark awarded			

1	2	3	4	5	6
Q. No.	**Mark**	**Coding options**	**Extra comments**	**Fine-grain mark**	**For all, code: 1 for mark, 0 for no mark**
	Mark 9 Arrow 3 source and sink	0 no answer **1 Curly arrow from O^- of correct intermediate to H in H_2O or H^+** 2 Curly arrow from O^- of correct intermediate but – sign and/or lone pair not identified to H in H_2O or H^+ 3 other	Identification of source and sink **Arrow must start from – sign or lone pair on O^-**	19	1,2 gain mark
	Arrow 3 position	0 no answer **1 Arrow close enough to correct source and sink** 2 Arrow wide of correct source ***or*** sink 3 arrow wide of both correct source ***and*** correct sink 4 other	1 or 2 above count as 'correct source'	20	1,2,3 gain mark
	Arrow 4 source and sink	**0 no answer** **1 curly arrow from OH bond to the O in H_2O** **2 not needed as H^+ used for arrow 3 above** 3 incorrect source ***or*** sink	No need to show OH^- Allow mark for curly arrow from O^- to H^+	21	1,2,3 gain mark

1	2	3	4	5	6
Q. No.	**Mark**	**Coding options**	**Extra comments**	**Fine-grain mark**	**For all, code: 1 for mark, 0 for no mark**
		4 incorrect source ***and*** sink 5 other			
	Arrow 4 position	**1 Arrow close enough to source and sink** **2 not needed as H^+ used for arrow 3 above** 3 Arrow wide of correct source ***or*** sink 4 arrow wide of both correct source ***and*** correct sink 5 other	Other if arrow in wrong direction for example	22	1,2,3,4 gain mark
	Mark 9 awarded?	0 no mark **1 mark awarded**			
2b(i)	**Mark 10** Enantiom er structure	0 no answer 1 correct structure 2 incorrect structure 3 other	Correct structure from mark 9  Any order, ignore attempts at 3d shape for this question	23	1 gains mark
	Mark 10 awarded?	0 no mark 1 mark awarded			
	Mark 11 Mirror image structures	0 no answer **1 correct structure as mirror image** 2 swapped 2 groups	Attempt at showing mirror images May be planar or 3d  	24	1,2,3 gain mark

1	2	3	4	5	6
Q. No.	**Mark**	**Coding options**	**Extra comments**	**Fine-grain mark**	**For all, code: 1 for mark, 0 for no mark**
		3 incorrect structure as mirror image 4 attempt at mirror image (correct or incorrect structure)but incorrect 5 other	Mirror does not need to be drawn. 'mirror' could be in any plane. Just swapping 2 groups without attempting to show mirror image does not get mark. e.g. 		
	Mark 11 awarded?	0 no mark 1 mark awarded			
2b(ii)			Point of attack/carbonyl/ molecule is planar	25	0 no answer 1 correct answer 2 incorrect answer
			Attack (by the nucleophile) can be from either side, front/back, left/right	26	0 no answer 1 correct answer 2 incorrect/missing answer
			Resulting in a chiral centre /chiral carbon/non superimposable enantiomers	27	0 no answer 1 correct answer 2 incorrect answer
3	**Mark 12**	0 no answer **1 A (correct answer)** 2 other		28	1 gains mark
	Mark 12 awarded?	0 no mark			

1	2	3	4	5	6
Q. No.	**Mark**	**Coding options**	**Extra comments**	**Fine-grain mark**	**For all, code:** **1 for mark, 0 for no mark**
		1 mark awarded			
4				29	0 no answer 1 H (correct answer) 2 other

Appendix C
Participant Questionnaire for Phases 1 and 2

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Participant Questionnaire

Participant information

Name and gender (M/F)

School/college

GCSE science qualifications (dual award or triple and grades)

Which A level subjects are you currently studying apart from chemistry?

In the table below please indicate the number of times, in the last four weeks, that you have done each type of activity in your chemistry lessons

	0	1-3	4-6	>6
Card sorting or other interactive paper based activity				
Group discussions				
Presentations				
Written work				
Answering examination questions				
Experimental work				

Part 2 - Learning

	Strongly agree	Agree	Disagree	Strongly disagree
I found the chemistry in this lesson easy to remember				
I found the chemistry in this lesson easy to understand				

Using drama* helped me to **remember** the chemistry theory in this lesson

Strongly agree	Agree	Disagree	Strongly disagree

Please give examples to support your answer

* For examination-style question group read 'practice examination questions' instead of 'drama'

Part 2 ctd - Learning

Using drama* helped me to **understand** the chemistry theory in this lesson

Strongly agree ☐ Agree ☐ Disagree ☐ Strongly disagree ☐

Please give examples to support your answer

Using drama* helped me to complete the examination questions

Strongly agree ☐ Agree ☐ Disagree ☐ Strongly disagree ☐

Please give examples to support your answer

* For examination-style question group read 'practice examination questions' instead of 'drama'

Appendix D
Materials relating to group interviews

D.1 Stimulus material used in group interviews for Phases 1 and 2

This section of Appendix D presents, on the subsequent pages, copies of the stimulus materials that were used by the researcher when conducting the group interviews in both Phase 1 and Phase 2.

What do you
remember about
the lessons taught
by Miss Otter?

Drama is a good way to help me understand chemical concepts

Using drama in chemistry lessons makes me uncomfortable

I am more likely to remember chemistry ideas by using exam questions than drama

By doing activities in lessons I am likely to remember the relevant chemistry

By acting out the chemistry myself I remember it

By writing my own script I am likely to remember the chemistry more than using someone else’s script

The drama activities helped me build a model of the reactions in my head

Working with a script confused me

It was easy to link the drama at the beginning of the lessons to the reaction mechanisms

When thinking about nucleophilic substitution reactions I am able to remember bits of the lesson relating to it

Using drama helped prepare me well for the exam questions

D.2 Stimulus material used in Phase 3 group interviews

This section of Appendix D presents, on the subsequent pages, copies of the stimulus materials that were used by the researcher when conducting the group interviews in Phase 3.

Using a pre-prepared script helped me **remember** the new chemistry

STRONGLY DISAGREE

NEITHER AGREE NOR DISAGREE

STRONGLY AGREE

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

Writing and acting my own script helped me to **remember** the new chemistry

STRONGLY DISAGREE | NEITHER AGREE NOR DISAGREE | STRONGLY AGREE

1	2	3	4	5	6	7	8	9	10

Using a pre-prepared script helped me **understand** the new chemistry

STRONGLY DISAGREE				NEITHER AGREE NOR DISAGREE					STRONGLY AGREE
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

Writing and acting out my own script helped me **understand** the new chemistry

STRONGLY DISAGREE | NEITHER AGREE NOR DISAGREE | STRONGLY AGREE

1	2	3	4	5	6	7	8	9	10

Using exam questions rather than drama helps me **remember** the new chemistry better

STRONGLY DISAGREE				NEITHER AGREE NOR DISAGREE					STRONGLY AGREE
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

Using exam questions rather than drama helps me **understand** the new chemistry better

STRONGLY DISAGREE				NEITHER AGREE NOR DISAGREE					STRONGLY AGREE
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

Using drama helps me **answer exam questions**

STRONGLY DISAGREE				NEITHER AGREE NOR DISAGREE					STRONGLY AGREE
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

I **enjoyed** using drama in my chemistry lessons

STRONGLY DISAGREE				NEITHER AGREE NOR DISAGREE					STRONGLY AGREE
1	2	3	4	5	6	7	8	9	10

D.3 Coding developed from the interpretation of group interview transcripts

This section of Appendix D presents tables detailing the coding developed through the analysis of the group interview transcripts.

D.3.1 Links between drama and chemistry

1 – Links between drama and chemistry	
	Code
Remembers physical aspect of drama	1.1
Remembers humorous aspects of drama	1.2
Links physical activity to chemistry	1.3
Links between 3D and 2D representations	1.4
Uses visualisation of chemistry to support chemistry recall	1.5
Watching drama is useful	1.6
Doing rather than watching is useful	1.7
Links drama to notes	1.8

D.3.2 Remembering

2 – Remembering	
	Code
Needed more than just drama to remember	2.1
Drama didn't help with remembering	2.2
Doing it yourself is useful for remembering	2.3
Helps with remembering, but I don't want to do it	2.4
Activity helps recall	2.5
Doing and watching are both helpful	2.6
Repetition was helpful for recall	2.7

D.3.3 Understanding

3 – Understanding	
	Code
Drama provides visualisation to aid understanding	3.1
Drama aids understanding	3.2
Drama not good for long term recall	3.2a
Drama assists with 2D to 3D thinking	3.2b
Drama is good for visualising the chemistry but does not help with answering exam questions	3.2c
Drama does not help with understanding chemistry	3.

D.3.4 Diagnostic question

4 – Diagnostic question	
	Code
Identifies complex demands of diagnostic question	4.1
Drama helps answer the diagnostic	4.2a
How drama helps answer the diagnostic	4.2b

D.3.5 Answering examination questions

5 – Answering examination questions	
	Code
Don't need to understand the chemistry to answer examination questions	5.1
Just need to remember the chemistry to answer exam questions	5.2
Predictability of exam questions	5.3
Exam technique is crucial for answering exam questions	5.4
Drama helps in answering exam questions	5.5
Need practice exam questions	5.6
Drawing mechanisms out is best practice for answering exam questions	5.7
Drama is good for learning the overall process, but not the detail	5.8
Evidence of progression from using drama to answer the examination questions to subsequent methods e.g. practice questions, revision	5.9
Drama a good way to introduce a new topic	5.10
Evidence of drama being used to directly answer examination questions	5.11

D.3.6 Scripts

6 – Script	
	Code
Lack of ownership of pre-prepared script	6.1
Sense of ownership of own script	6.2
Own script helped in answering examination questions	6.3
Pre-prepared script helped as there was repetition	6.4
Needed to concentrate on writing own script	6.5
Own script encourages own understanding	6.6
Need to focus	6.7
Concerns re getting chemistry correct when writing own script	6.8
There can be a tendency to silliness in group work	6.9

Appendix E
Ethics Approval

E.1 Approval for the pilot and Phase 1

Performance, Governance and Operations
Research & Innovation Service
Charles Thackrah Building
101 Clarendon Road
Leeds LS2 9LJ Tel: 0113 343 4873

Email: ResearchEthics@leeds.ac.uk

UNIVERSITY OF LEEDS

Christine Otter
School of Education
University of Leeds
Leeds, LS2 9JT

ESSL, Environment and LUBS (AREA) Faculty Research Ethics Committee

University of Leeds

Dear Christine

Title of study:	**Is drama a useful tool in teaching and learning of organic reaction mechanisms in A level chemistry?**
Ethics reference:	**AREA 14-038, response 2**

I am pleased to inform you that the above research application has been reviewed by the ESSL, Environment and LUBS (AREA) Faculty Research Ethics Committee and following receipt of your response to the Committee's comments, I can confirm a favourable ethical opinion as of the date of this letter. The following documentation was considered:

Document	Version	Date
AREA 14-038 Chris Otter response 3 to AREA 14-038.docx	1	05/12/14
AREA 14-038 Chris Otter Dear Parent.docx	1	05/12/14
response to AREA 14-038 Committee Provisional.doc	1	26/11/14
AREA 14-038 finalmainstudyethicsapprovaloct2014.docx	1	26/10/14
AREA 14-038 focus group statements.docx	1	26/10/14
AREA 14-038 main study risk assessment.CAO.doc	1	26/10/14
AREA 14-038 main_study_ChrisOtter_Headteacher_consent_request.docx	1	26/10/14
AREA 14-038 main_study_ChrisOtter_student_consent_form.docx	1	26/10/14
AREA 14-038 main_study_ChrisOtter_student_questionnaire.pptx	1	26/10/14
AREA 14-038 main_studyChris_Otter_Teacher_notes_to_read_to_students_1_week before pilot study.docx	1	26/10/14

Please notify the committee if you intend to make any amendments to the original research as submitted at date of this approval, including changes to recruitment methodology. All changes must receive ethical approval prior to implementation. The amendment form is available at http://ris.leeds.ac.uk/EthicsAmendment.

E.2 Approval for Phases 2 and 3

Performance, Governance and Operations
Research & Innovation Service
Charles Thackrah Building
101 Clarendon Road
Leeds LS2 9LJ Tel: 0113 343 4873

Email: ResearchEthics@leeds.ac.uk

UNIVERSITY OF LEEDS

Christine Otter

School of Education

University of Leeds

Leeds, LS2 9JT

AREA Faculty Research Ethics Committee

University of Leeds

Dear Chris

Title of study:	**Is drama a useful tool in teaching and learning of organic reaction mechanisms in A level chemistry?**
Ethics reference:	**AREA 14-038, amendment Nov 2015**

I am pleased to inform you that your amendment to the research application listed above has been reviewed by a representative of the ESSL, Environment and LUBS (AREA) Faculty Research Ethics Committee and I can confirm a favourable ethical opinion as of the date of this letter.

The following documentation was considered:

Document	*Version*	*Date*
AREA 14-038 amendment Nov 15 ChrisOtterAmendment_form.docx	1	19/11/15
AREA 14-038 amendment Nov 15 further info.txt (by email)	1	25/11/15
AREA 14-038 amendment Nov 15 Headteacher_consent_request.docx	1	19/11/15
AREA14-038ChrisOtterAmendment_form.docx	1	17/12/14
AREA 14-038 amendment Dec 2014 notes_to_read_to_students_2_weeks_before_questionnaire.docx	1	17/12/14
AREA 14-038 amendment Dec 2014 informing_parents_of_study.docx	1	17/12/14
AREA 14-038 amendment Dec 2014 student_consent_form.docx	1	17/12/14
AREA 14-038 amendment Dec 2014 Headteacher_consent_request.docx	1	17/12/14
AREA 14-038 Chris Otter response 3 to AREA 14-038.docx	1	05/12/14
AREA 14-038 Chris Otter Dear Parent.docx	1	05/12/14
response to AREA 14-038 Committee Provisional.doc	1	26/11/14
AREA 14-038 finalmainstudyethicsapprovaloct2014.docx	1	26/10/14
AREA 14-038 focus group statements.docx	1	26/10/14
AREA 14-038 main study risk assessment.CAO.doc	1	26/10/14
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AREA 14-038 main_study_ChrisOtter_student_consent_form.docx	1	26/10/14
AREA 14-038 main_study_ChrisOtter_student_questionnaire.pptx	1	26/10/14
AREA 14-038 main_studyChris_Otter_Teacher_notes_to_read_to_students_1_week before pilot study.docx	1	26/10/14

Please notify the committee if you intend to make any further amendments to the original research as submitted at date of this approval as all changes must receive ethical approval prior to implementation. The amendment form is available at http://ris.leeds.ac.uk/EthicsAmendment.