Developing Oracy to Learn Chemistry in the Secondary School Laboratory

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A thesis submitted for the degree of PhD (by prior publication)

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University of East Anglia

December 2023

Declaration of Originality

This is to certify that to the best of my knowledge; the content of this thesis is my own work. This thesis has not been submitted for any degree or other purposes. I certify that the intellectual content of this thesis is mine and that all the assistance received in preparing this thesis and sources have been acknowledged.

Naomi Louise Hennah
December 2023

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Naomi Louise Hennah

Abstract

Oracy is the ability to express oneself effectively in spoken language, and developing oracy in lessons has been shown to deepen understanding and improve test scores. In schools, students work together in groups to carry out hands-on practical tasks which are introduced, conducted, and reviewed using spoken language. Although practical work is integral to teaching and learning in school chemistry, its efficacy in meeting its intended goals has been contested. Interventions designed to improve student attainment in practical-themed exam style questions, which employ processes for developing oracy as a tool for learning in the laboratory, are discussed.

The publications presented here, document the practice-orientated research conducted by a teacher in response to changes to the English National Curriculum. A PhD by publication thesis includes a critical analysis of the published work, and here both the academic and professional implications are considered alongside the circumstances that prompted the research. With methodologies that draw upon sociocultural theory and cognitivism, this research describes how the intervention activities were organised, student perceptions and quantitative analysis of attainment data.

Paper 1 reports positive affective outcomes from students and teachers employing a digital badge protocol to learn laboratory techniques. Exemplar video provides pre-laboratory preparation before students film each other narrating and demonstrating laboratory techniques, and verbal feedback is provided when the recordings are reviewed and judged against the badge criteria. However, the students were seen to lack the confidence and oracy skills required to coherently articulate what they were doing and why.

Paper 2 employs a quasi-experimental approach to determine the impact of the digital badge protocol on student attainment. This iteration of the digital badge protocol explicitly seeks to develop oracy by including a prompt slide that scaffolds student talk during the practical task. Both positive affective outcomes and a greater retention of procedural information are reported.

Paper 3 describes a modified pre-laboratory preparation video with two voice overs that separates procedural information from the underlying concepts with the aim of reducing the cognitive load of the activity. Through the application of cultural-historical activity theory, division of labour is identified as problematic. So, both Lab Roles and Lab Talk were introduced to scaffold student interactions to facilitate collaboration and the joint construction of knowledge. Positive affective outcomes and increased attainment in practical-themed exam style questions are reported.

A sociocultural linguistic approach is adopted in the case study in Paper 4, which describes the language used to teach and learn about acids and alkalis in a chemistry lesson for students aged 11 and 12 years old. This approach considers learning chemistry to be a discursive process in which knowledge is constructed through social interaction and language. Thus, learning may be identified by attending to the language used in classroom discourse. This approach offers insight into problematic language, recasting a table of results as a talk scaffold, and demonstrates the use of talk moves for the direct assessment of practical task effectiveness.

The critical analysis closes by considering the meta-learning that had occurred as the work progressed and identifies a shift in ontological and epistemological positioning that has occurred in conjunction with the increasing emphasis on developing oracy. The reflection closes with a comparison between the planning and delivery of a practical chemistry lesson before and because of the research process.

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Acknowledgements

I have been teaching science with a chemistry specialism for twenty years because I love the subject, and I believe that education is the pathway to equity and social justice. Young people need a strong foundation in science to make informed decisions about their lives and the world around them.

Neo-liberal education policy employs statistical and forecast tools of governance which recast young people as data, with the concomitant erosion of teachers' classroom agency, authority, and autonomy. Schools risk becoming exam factories in which teachers just train students to regurgitate curriculum content to meet or exceed forecast targets in high stakes examinations. An approach reminiscent of that espoused in Hard Times (Dickens 1854) by the educator with a rationalist philosophy of self-interest, Mr Gradgrind.

"Now, what I want is Facts. Teach these boys and girls nothing but Facts. Facts alone are wanted in life. Plant nothing else, and root out everything else. You can only form the minds of reasoning animals upon Facts; nothing else will ever be of any service to them." (p. 1)

Demoralised by opinions and policies that I was powerless to change, I sought to better support my students and develop agency in this climate of accountability. I found that practice-oriented research empowered me as a teacher and developed my academic identity. However, this has only been possible because of the help and support provided by the following people, to whom I owe a debt of gratitude.

I would like to thank my University of East Anglia Supervisors, "My Professor" Simon Lancaster, and Professor Kay Yeoman, for their time and guidance in helping me to get this over the finish line.

My thanks must also be given to the school and its community, for their contributions and forbearance in supporting the accomplishment of this work.

I am most profoundly grateful and forever indebted to Professor Michael Seery for his help, encouragement, and endless patience.

Michael, if you ever put out another call for interested partners *"timeo Danaos et dona ferentes"*[1] because some gifts go on, go on, go on…

Finally, I'd like to thank my wonderful family for their stoicism while I pursued and shared my interests. Without you all, I would have no sense of achievement; you make me proud.

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[1] phrase from Virgil's Aeneid (II, 49)

List of Publications and Academic Impacts

Paper 1	Hennah, N. & Seery, M. K. (2017). Using digital badges for developing high school chemistry laboratory skills. *Journal of Chemical Education*, 94(7), 844–848.
Author's contribution	The first author's contribution: • Alignment of the badging resources with the A level chemistry curriculum • The plan and design of the project • Collecting data • Analysing the data The second author's contribution • Provided the badging resources. • Analysis and presentation of data • Lead writer for the paper

Other impacts	**Citations (Google scholar)**	**Altmetric**
ACS Editor's Choice 9581 article views Featured in RSC *Education* in Chemistry magazine Included in *Journal of Chemical Education* virtual issues Marcy H. Towns Festschrift and 100 Years of Teaching and Learning: High School Chemistry [2]	46	18 (top 25%)

Paper 2	Hennah, N. (2019). A novel practical pedagogy for terminal assessment. *Chemistry Education Research and Practice*, 20(1), 95–106.
Author's contribution	A single author publication detailing work designed and carried out by the author alone. Manuscript proofread by M.K. Seery

Other impacts	**Citations (Google scholar)**	**Altmetric**
Featured in RSC *Education in Chemistry* magazine. Poster presented at Methods in Educational research 2017	7	22

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[2] The authors work featured in the RSC *Education* in Chemistry Magazine can be accessed [Online] https://edu.rsc.org/searchresults?qkeyword=Naomi+Hennah&forcemicrositenavcode=124&parametrics=WVMICROSITEROOTNAVCODE%7C124%2CWVFACET5%7C115501

<table>
<tr><td>Paper 3</td><td colspan="3">Hennah, N., Newton, S., & Seery, M. K. (2022). A holistic framework for developing purposeful practical work. <i>Chemistry Education Research and Practice.</i> 23(3), 58–598.</td></tr>
<tr><td>Author’s contribution</td><td colspan="3">The first author’s contribution
• The plan, design, and implementation of the project
• Collection and analysis of data
• Lead writer for the paper
• Executing the submission process
The second author’s contribution
• Made and produced “one video two voice over” videos.
The third author’s contribution
• Author two’s supervisor
Guiding and proofreading the manuscript</td></tr>
<tr><td colspan="2">Other impacts</td><td>Citations (Google scholar)</td><td>Altmetric</td></tr>
<tr><td colspan="2">Featured in RSC <i>Education in Chemistry</i> magazine.
Speaker at:
Methods in Chemistry Research 2018 (invited)
University of Southampton Post-16 Chemistry Teachers' Conference 2018 (invited)
2018 The Open University School of Life, Health, and Chemical Sciences Educational research group (invited)
2019 ASE annual conference
Speak for Change Parliamentary inquiry evidence 2020 (invited)
Poster presented at:
Methods in Chemistry Research 2018
CLEAR Lab Symposium 2020
RSC online poster competition 2018 and 2019</td><td>6</td><td>22</td></tr>
</table>

<table>
<tr><td>Paper 4</td><td colspan="3">Hennah, N. (2023) “What are they talking about?” A sociocultural linguistic approach to practical task effectiveness. <i>Chemistry Education Research and Practice,</i> 24(2), 637–658</td></tr>
<tr><td>Author’s contribution</td><td colspan="3">A single author publication detailing work designed and carried out by the author alone.
Manuscript proofread by M.K. Seery</td></tr>
<tr><td colspan="2">Other impacts</td><td>Citations (Google scholar)</td><td>Altmetric</td></tr>
<tr><td colspan="2">Speaker at:
ChemEd Ireland 2022 (Keynote)
West of Scotland Meeting for Teachers of Chemistry 2023 (Keynote)</td><td>0</td><td>4</td></tr>
</table>

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Preface

The structure of the thesis

A PhD by publication combines prior published work with a critical analysis. The four papers submitted as evidence in this thesis are detailed above. The thesis is arranged so that each chapter presents a critical reflection of one paper, and the closing chapter presents a critical review of the meta-learning resultant from the body of work.

I am a schoolteacher carrying out educational research to empower my professional practice with a legitimised academic voice. This work may be defined as practice-oriented research as it was designed to contribute to chemistry education research and chemistry education (Groothuijsen *et al*., 2020). It is therefore important that the critical analysis emphasises both the academic and practical impact of each of the research episodes. To achieve this, I have adopted the Driscoll model of critical reflection.

Driscoll's (2007) 'What?' model of critical reflection asks: What? So what? What now? and suggests that answering these three questions is a metacognitive process that facilitates learning from an experience. The term experience is used here to refer to the research experience and places equal value on my development as a researcher and practitioner.

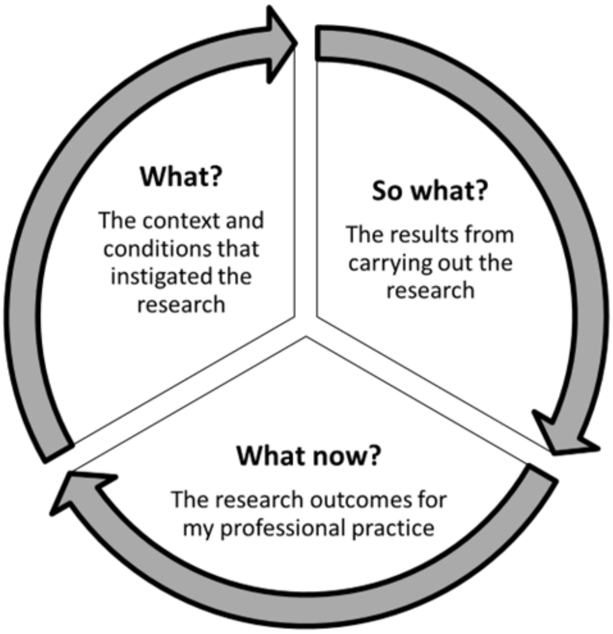


Figure P.1, chapter subdivisions informed by Driscoll's (2007) 'What?' model of critical reflection.

Chapters 1 to 4 consider one paper each. Each chapter is subdivided into three parts: “What?” describes the context and conditions that instigated my research, “So what?” identifies methodological considerations and results, and “What now?” considers the impact of the work on my professional practice.

Chapter 5 considers meta-learning and asks; What impact has practice-oriented research had on my understanding of school chemistry education? So, what was the impact of practice-oriented research on my ontology and epistemology? What now? compares my laboratory pedagogy before and after undertaking practice-oriented research.

Science education in England

The context of this research is formal education and takes place in an 11-16 Boys’ academy with a mixed post-16 intake, situated in England’s East Midlands. The school has elected to follow the National Curriculum which is divided into age defined programmes of study and attainment targets called Key Stages. The study of science is compulsory up to and including the General Certificate of Secondary Education (GCSE) which is the academic qualification examined at the end of Key Stage 4. After which, students can elect to continue to study chemistry at the Advanced Level (A-Level).

This work is concerned with the study of chemistry as presented by the science programmes of study, specifically with the execution of practical tasks associated with this content (UK Government 2015 a). The publications presented in this thesis and the stage of science education in which they have taken place are summarised in Figure P.2.

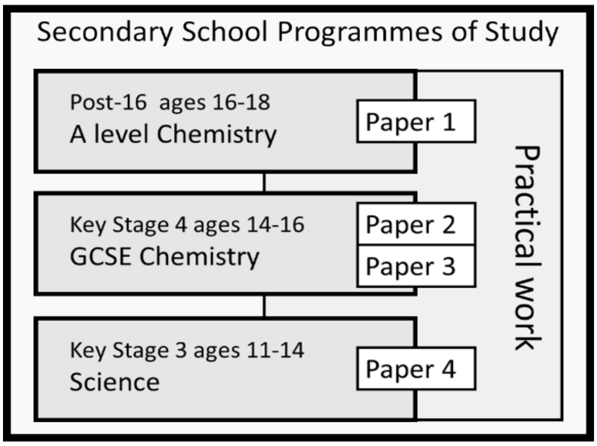


Figure P.2, the structure of the English secondary school science curriculum and the location within which each paper is situated.

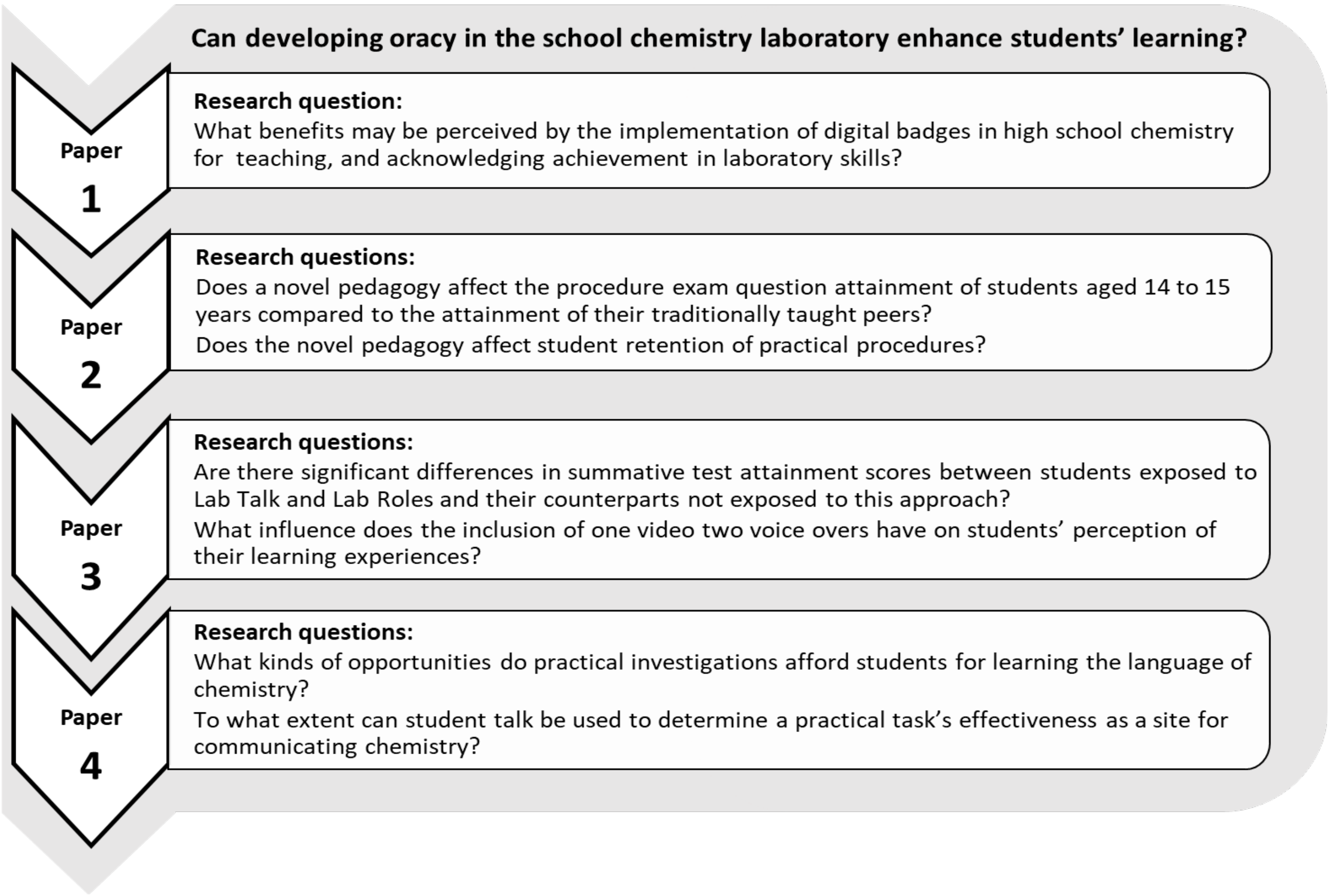
Overarching research question

Teaching and learning in the school laboratory are the central concern of this work, but as the research described in Papers 1 to 4 progressed, the importance of language and communication became increasingly apparent.

The overall aim of the work submitted in this thesis is to explore students' laboratory work in an English secondary school and the purpose is to develop oracy in the school chemistry laboratory as a teaching and learning tool. Figure 3 situates the research questions from each paper within the overarching research question.

The overarching research question in this thesis is:

- Can developing oracy in the school chemistry laboratory enhance students' learning?



Can developing oracy in the school chemistry laboratory enhance students' learning?

Research question:
What benefits may be perceived by the implementation of digital badges in high school chemistry for teaching, and acknowledging achievement in laboratory skills?

Research questions:
Does a novel pedagogy affect the procedure exam question attainment of students aged 14 to 15 years compared to the attainment of their traditionally taught peers?
Does the novel pedagogy affect student retention of practical procedures?

Research questions:
Are there significant differences in summative test attainment scores between students exposed to Lab Talk and Lab Roles and their counterparts not exposed to this approach?
What influence does the inclusion of one video two voice overs have on students' perception of their learning experiences?

Research questions:
What kinds of opportunities do practical investigations afford students for learning the language of chemistry?
To what extent can student talk be used to determine a practical task's effectiveness as a site for communicating chemistry?

Figure P.3, the research questions from each publication situated within the overarching thesis research question.

Clarification of terms

The terms practical work, practical task, and laboratory work are used synonymously and can be understood here to refer to all types of science teaching and learning, where students that are working alone or in small groups are handling equipment and materials (Abrahams & Reiss 2012).

Oracy is used here to refer to the development of learners' speaking and listening skills (Wilkinson 1965). The National Curriculum for science identifies the importance of spoken language to learners' cognitive, social, and linguistic development (UK Government 2015 a).

School accountability is the "practice of holding educational systems responsible for the quality of their products – students' knowledge, skills and behaviors" (Stecher & Kirby 2004, p. 1). In England school performance measures are calculated annually to hold state-funded schools to account and to support parental school choice.

Learning modalities are the different ways in which people use their senses to process information and learn. For example, in cognitive load theory, the modality effect describes how mixed mode (part visual and part auditory) presentation of information is more effective than when the same information is presented as either visual or auditory alone.

Multimodality considers how different representational modes, for instance, between images and written/spoken word are combined in the communication process (Kress 2012).

Modality Effect describes an increase in working memory capacity brought about by presenting both pictorial and verbal information together so that both visual and auditory systems process the information rather than either processor alone (Sweller, van Merriënboer, & Paas 2019).

Chapter 1: Using digital badges for developing high school chemistry laboratory skills.

<table>
<tr><td>Paper 1</td><td colspan="2">Hennah, N. & Seery, M. K. (2017). Using digital badges for developing high school chemistry laboratory skills. <i>Journal of Chemical Education</i>, 94(7), 844–848.</td></tr>
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9581 article views
Featured in RSC <i>Education</i> in Chemistry magazine</td><td>43</td><td>18 (top 25%)</td></tr>
</table>

What circumstances led to Paper 1?

The 2010 reforms to the National Curriculum for England were greeted with concerns that a curriculum policy framed by international benchmarking, and high stakes accountability as measured by pupil performance would result in schools prioritising examined parts of the curriculum; teaching to the test (Brill *et al.,* 2018).

In 2015 the practical endorsement was introduced into science education which separated the direct assessment of practical skills from the primary A level grade. Formally 20 percent of the total marks for A level chemistry had been available prior to the exams through practical assessments. Now all the assessment would take place through terminal exams in which 15 percent of the total marks would be allocated to questions that indirectly assess practical skills. These questions may concern the practical procedures named in the specification or require the understanding of an aspect of a practical procedure to answer a question about the underlying science (AQA 2017).

The move was viewed by many stakeholders as deprioritising practical work (see for example: Gatsby 2014; Ofqual 2013; Wellcome Trust 2014). For example, students, who often feel that assessment defines the actual curriculum (Reiss & Abrahams 2015), may resent time spent on unassessed practical work because of the increased pressure on exam performance. Furthermore, only England had adopted this approach so our students would be competing for university places with students from other regions of the British Isles that had retained coursework or controlled assessment.

The controversy surrounding the curriculum reforms compelled me to identify my personal concerns about teaching the reformed curriculum and to anticipate possible impacts on students. I hypothesised that by identifying the issues, I could begin to find ways of mitigating negative outcomes. I began by questioning why practical work was important to me, and why I felt that it was an important component of teaching chemistry.

The purposes I attribute to practical work can be represented by the Taxonomy of Learning Domains; cognitive (Anderson *et al*., 2001), affective (Krathwohl *et al*., 1964), and the psychomotor (Harrow 1972) which align closely to the aims identified by Jenkins (1999). Practical work should engage and develop all three learning domains if students are to gain the knowledge, impetus and transversal skills needed for employment:

- Cognitive, to support students’ development of knowledge, understanding, and experience of chemistry.
- Affective, to increase students’ interest in, and engagement with chemistry.
- Psychomotor, to provide students with the opportunity to practise handling special equipment; using standard techniques; comprehension and execution of instructions.

From my perspective as a chemistry teacher in a climate of accountability, the changes to practical assessment moved the purpose of practical work out of the laboratory, and into the exam hall. The reformed exam specification names the apparatus and techniques that students should experience, but the exams test the student’s knowledge and understanding of them (AQA 2017). In doing so, psychomotor skills and transversal skills are devalued whilst placing greater emphasis on recall and literacy. The purpose of practical work seemed to transform from developing learning domains into providing a context for indirect assessment, as illustrated in Figure 1.1.

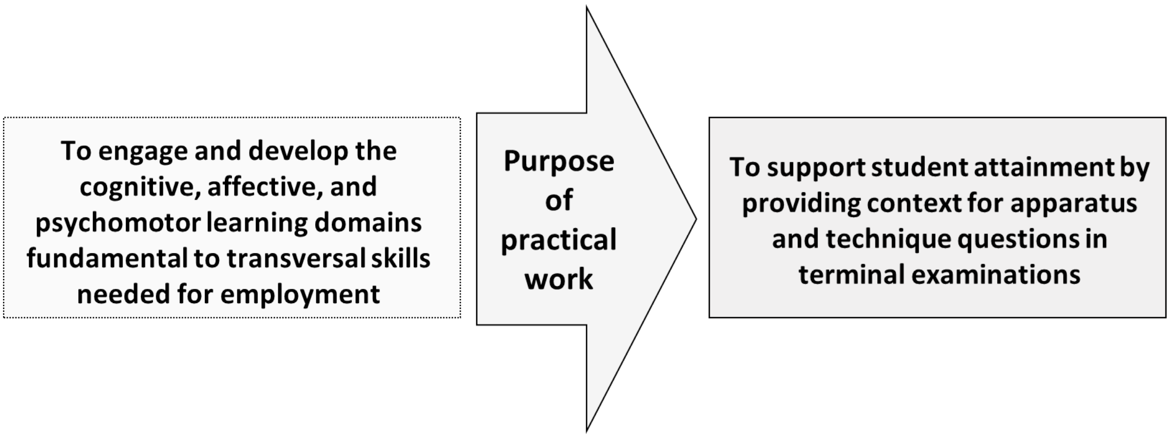

Figure 1.1, the purpose of practical work seems to have shifted away from situational learning towards providing the context for practical-themed exam questions.

The reforms had not changed my values, instead I sought to modify my own professional practice so that my purposes could be met whilst supporting students to succeed in the reformed assessment. It was because of this preoccupation that I was interested in Michael Seery's "Badging Lab Skills" work on the development of laboratory techniques and Digital Badge[3] rewards. I modified the Badging Lab Skills materials, so they met the A level assessment criteria, and introduced the A level students to the badging protocol, which is summarised in Figure 1.2, to address the research question: what benefits may be perceived by the implementation of the digital badge protocol in high school chemistry for teaching, and acknowledging achievement in laboratory skills?

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[3] Badging Lab Skills [online] https://badginglabskills.wordpress.com/about/

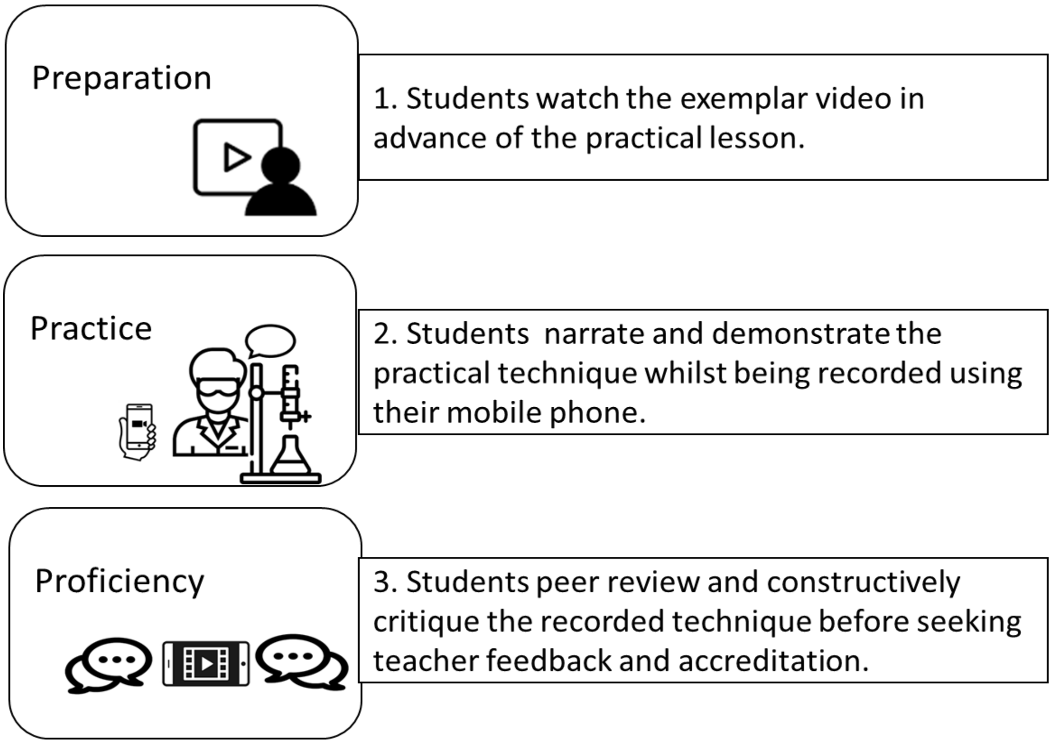

Figure 1.2, a summary of the three stages of the A level chemistry badging process described in Paper 1. Students put into practice the technique shown in the exemplar video and a recording of their work is used to assess their proficiency.

So, what benefits were perceived by implementing the digital badge protocol?

The digital badge protocol required that students watched exemplar videos prior to the practical lesson to help prepare them to demonstrate specific techniques within the activity. In the lesson, as one student demonstrated and narrated a laboratory technique to a peer, their peer videoed the demonstration on a mobile phone and then the roles were reversed. This video was then used to review the demonstration by both peers and teacher, and once the technique was considered satisfactorily demonstrated, a digital badge was awarded.

The digital badge protocol emphasises the development of laboratory technique and facilitated the formal incorporation of oracy into the practical task. Furthermore, reviewing the recordings required discussion between peers and between student and teacher, so that the protocol aims to maximise time for discussion and dialogue.

To assess the benefit of the digital badge protocol, mandatory surveys were given to the students as part of a task booklet. The surveys used a 5-point Likert scale to gain an understanding on how the activity was perceived. The surveys included a combination of both open and closed questions. Closed questions are of limited value as they only provide information about the offered options whereas, open questions enable the respondent to express their view. However, most participants chose to leave the open questions unanswered which limited the validity and reliability of the questionnaires (Joshi *et al*., 2015). A judgement of how the digital badge protocol worked in practice was made from a combination of the students' responses and observation data.

The protocol caused a shift in focus away from the experiment being a result generating event, towards identifying techniques within the procedure that students had to think about what they were doing and why. Indeed, several students commented on how much more confident and knowledgeable they felt about carrying out a titration than they had previously, and that they had gained an understanding of why the technique is used. What also became apparent was that the students lacked the confidence and the vocabulary to clearly articulate the technique.

Paper 1 was very well received by the chemistry education research community and adds to the body of work exploring how to improve laboratory education. The digital badges offer a means of recording and accrediting students' proficiency with instrumentation and equipment. The badges in combination with pre-laboratory videos and peer-assessment rubrics, have been reported to have a positive impact on students' self-concept of ability (Harwood *et al*., 2020; Keiner & Graulich 2021).

Paper 1 may be described as a practice paper that provides an account of the pedagogical approach opposed to an empirical study that collects and analyses data (Taber 2016). Understanding cognitive effects and indirect assessment attainment are crucial in a culture of educational accountability to persuade colleagues to adopt an alternative pedagogy. Thus, further work that combines psychometric data with additional measures of student learning outcomes may produce a more robust argument (Lawrie 2022).

What now for my professional practice?

What sparked my interest in trialling Michael Seery's (2016) badging resources was the similarity between his digital badge protocol and task analysis (Moyer & Dardig 1978). Task analysis is a learning support approach and refers to the process of breaking a complex task into a sequence of smaller, more manageable actions that need to be completed, one by one, to reach a specific goal.

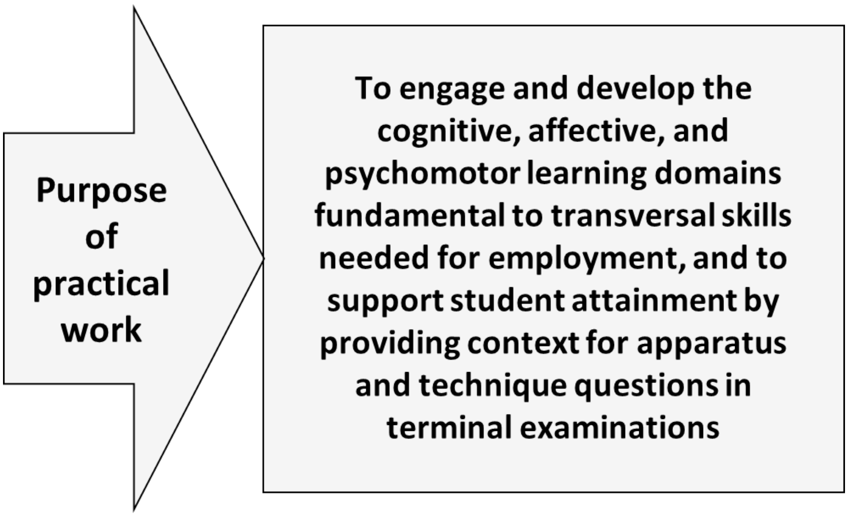

Figure 1.3 illustrates my perception that the digital badge protocol provides a mechanism for meeting both my aim of supporting the three learning domains AND supporting student examination attainment.

Using the digital badge protocol, titration was simplified into a series of steps: making a standard solution, using a pipette, and using a burette; each of these were demonstrated and explained. This would provide the experience of the apparatus and technique required for the A level practical endorsement and develop the knowledge and understanding required by learners to successfully answer the indirect assessment exam questions. I felt that this approach to laboratory work would support learners' indirect assessment attainment and provided a mechanism for development in the three domains of learning as illustrated in Figure 1.3.

It is now my custom to ask A level students to watch an exemplar video before a practical lesson and to complete a preparatory activity such as writing a risk assessment or answering questions about the procedure, this is summarised in Figure 1.4. Another significant outcome was identifying the need to develop oracy skills to promote metacognition and to improve communication and linking of ideas.

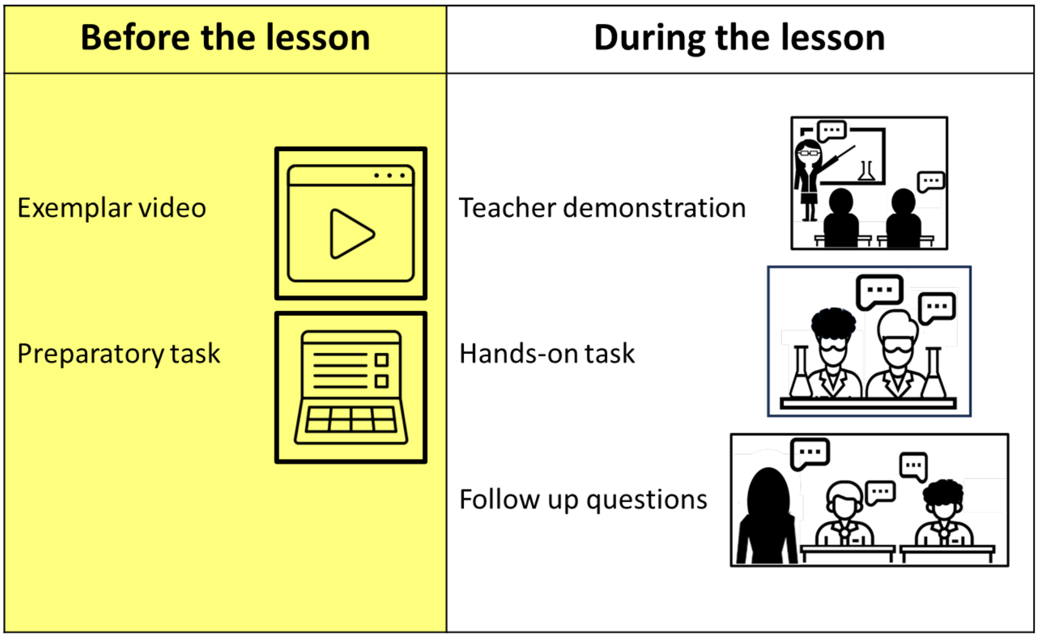

Figure 1.4 summarises my approach to A level practical work following the work described in Paper 1. The highlighted column identifies the new inclusion of pre-laboratory preparation.

Other professional impacts

The digital badge technology had the potential to make direct assessment of practical skills of large numbers of students viable (Sund 2016). Digital badges provide a portable record that can include evidence, which could accompany students when they move between Key Stages and schools, to facilitate a smooth transition. Understanding the potential of this technology, I mapped out the development of the scientific methods and skills identified throughout the National Curriculum for Science in England. I looked at the progressions of both the scientific competencies and the language needed to articulate the protocol steps. I then trialled the framework with primary school children (Hennah 2019) and described and explained digital badges and a progression of scientific competencies from age 5 to 18 (Hennah 2018 a; Hennah 2018 b). This work is available in the Appendix.

Confident that pre-laboratory preparation using videos was beneficial, I contacted the RSC to suggest making laboratory preparation videos to support A level students. This resulted in my involvement and authorship in the practical skills quizzes and videos which are freely available on the RSC Teach Chemistry website.

Other professional impacts	**Audience**
Developing Oracy Skills: a method to improve comprehension and acquisition of the language of chemistry, Poster presented at Methods in Chemistry Education Research, 2017	Chemistry Educators and researchers from schools and HE
Introducing oracy as a strand of the school development plan Whole staff training September 2017	All teaching staff across the school including senior staff
Why we need oracy, teacher training November 2017	Teachers representing every department across the school
Hennah, N. (2018a). Open Badges Part 1: What, Why, How? *School Science Review*, 100(371), 76-80.	Primary and secondary school science educators
Hennah, N. (2018b). Open Badges Part 2: The 'Working Scientifically' Framework. *School Science Review*, 100(371), 81-90.	Primary and secondary school science educators
Hennah, N. (2019). Open Badges Part 3: Framework and Strategies in Action. *School Science Review*, 100(372), 76-85.	Primary and secondary school science educators
RSC Practical Skills assessment [Online] https://edu.rsc.org/resources/qualitative-analysis-quizzes/2201.article	A level chemistry teachers and students
RSC A level video [Online] https://edu.rsc.org/practical/practical-videos-16-18-students/4012343.article	A level chemistry teachers and students
Frame, R., Hennah, N., and Seery, M.K., When teachers and researchers collaborate, *Education in Chemistry* [online] 16 January 2018. Available at https://edu.rsc.org/ideas/when-teachers-and-researchers-collaborate/3008524.article	Education in Chemistry magazine readers

JOURNAL OF CHEMICAL EDUCATION

Article

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Using Digital Badges for Developing High School Chemistry Laboratory Skills

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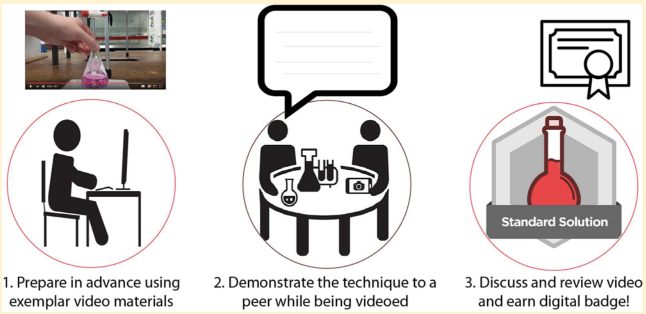
Ⓢ *Supporting Information*

ABSTRACT: Digital badges are emerging as an approach to offer microaccreditation for student achievements obtained in ongoing course work. They act to offer a formal recognition and framework for multiple small components which together make a significant contribution to student learning. Badges are promoted as a way of highlighting these particular components. The process of awarding a badge relies on evidence, typically in digital form, such as video. In this article, we report on the implementation of digital badges in high school chemistry for the teaching and accrediting of achievement in laboratory skills. Pupils watched videos prior to the classroom to assist them in preparation for a demonstration activity. In the classroom, students demonstrated the laboratory technique to a peer while the peer videoed the demonstration on a mobile phone. This video was then used to review the demonstration by both peers and teacher, and once the technique was considered satisfactorily demonstrated, a badge was awarded. As well as development of laboratory technique, the badging process facilitated the formal incorporation of oracy into the classroom. Demonstration required narration, and review required discussion between peers as well as discussions arising out of the demonstration with the teachers. We report here how the activities were organized, along with perceptions from students and teachers regarding the value of this approach in the classroom.



KEYWORDS: *High School/Introductory Chemistry, First-Year Undergraduate/General, Laboratory Instruction, Communication/Writing, Hands-On Learning/Manipulatives, Multimedia-Based Learning, Testing/Assessment, Quantitative Analysis*

■ INTRODUCTION

Practical work in schools has a long history and is the subject of extensive debate. In the United Kingdom, research into practical work in schools has found that pupils entering university often do not have confidence in completing practical work,[1] a fact attributed to reduced emphasis and exposure to practical work.[2] Employers surveyed by the Gatsby Foundation reported that, among a variety of skills, some core generic skills were important, including “analyzing and interpreting data to provide good evidence, and recording measurements with accuracy and precision”.[1,3]

Digital badges are an emerging educational technology which aim to recognize learning, often in informal environments, across school, university, and professional education.[4] While the concept of badging is well-understood from its use in the Guiding and Scouting movements, their incorporation in education is nascent, with scholarly work regarding their use in STEM education being relatively recent.[4,5] As well as recognizing competencies regarding specific achievements, digital badges have been proposed as a means to develop an *ecosystem* upon which a range of related concepts can be built.[6] The use of badges has recently been reported in secondary STEM[5] and university chemistry[7] education. Recently, the engineering company Siemens introduced their own badges framework to encourage the take-up of STEM studies among school pupils.[8]

Digital badges are built on the concept of display of evidence of a particular competency or skill that the badge is acknowledging. Given the digital nature of the badge, the corresponding evidence is also often in digital form.[9] Video evidence has been used as a means of documenting evidence for laboratory skills in chemistry.[7] Video evidence is of interest as it incorporates an additional aspect into learning about practical techniques: oracy. The process of producing a video means that pupils will need to speak about the technique they are describing, and to use scientific terminology in context. The concept of oracy emerged in the 1960s amid concerns that the spoken language was being neglected in education.[10] One of the reasons proposed for its neglect is a practical one; a typical classroom setting may impose difficulties in managing and teaching oracy. More recently efforts have been made to incorporate discussion and dialogue into education, although its

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focus has been biased toward initial years in school.[11] Despite its challenges, laboratory education does provide a platform for engaging pupils in speaking and listening activities, especially regarding language of scientific discourse.[11] This, coupled with the use of video, means that discussions can take place, as well as reviews of spoken work. The approach has the potential to be a very powerful one indeed.[11]

The purpose of this report is to describe the integration of a digital badging activity in a school laboratory setting. Previous work on the use of digital badges in higher education involved the demonstration of a particular skill by teaching assistants[7a,b] or by using exemplar technique videos.[7c] The advantage of using exemplar videos as prelaboratory work is that pupils can watch how the technique was completed in their own time, and the method offers them as much time as they need to study the technique in advance of the laboratory. Prelaboratory videos have been proposed as a means of reducing cognitive load in laboratories, by presenting some of the information in advance of class time.[12]

Part of the syllabus for the Oxford, Cambridge, and Royal Society of Arts (OCR) examination board, one of the examination organizations in operation in England and Wales responsible for assessment of high school subjects at a national level, details practical work outcomes (called specifications) for the school leaving qualification undertaken by pupils above aged 16, called the A level.[13] Included in this are the following details regarding practical skills associated with the acid−base titration:

- Measurement of a volume of a liquid
- Use of volumetric flask, including accurate technique for making up a standard solution
- Titration, using buret and pipet
- Use of acid−base indicators in titrations of weak/strong acids with weak/strong bases

This specification information was used as the basis for the activities in this report. The skills involved included weighing, pipetting, making up solutions in a volumetric flask, and using a buret to titrate their solution. The activities were designed so that they formed a sequence of lessons, each of which provided the opportunity to focus on one technique, but also to revisit a technique previously developed. The three activities are

1. To prepare a standard solution of sodium carbonate in a 250 cm^3 volumetric flask
2. To prepare a diluted solution of vinegar using a volumetric pipet and volumetric flask
3. To perform a titration of sodium carbonate with sulfuric acid. This activity acted as a "capstone" by including the requirement for preparation of a standard solution, and using a volumetric pipet

Most pupils completing their A levels will have prior knowledge of these methods and calculations for their intermediate school work in preparing for a midschool examination (the General Certificate of Secondary Education). Typically they will have used a pipet and buret 2−3 times by the time they begin A level work. In the earlier stages, the focus is on the overall approach rather than the specific details of the techniques. They will have little concept of what "analysis" is and the impact of accuracy and precision.

METHOD

The activities were run with 2 classes: The first class had 19 pupils, and the second class had 20 pupils. Both classes were "Year 12"; the first year of the final two years at school in which pupils study for their A levels.

Each student had to prepare in advance by watching a video showing exemplary technique and answering a series of questions related to the video and the procedure it demonstrated. The pupils also had copies of the actual method they would be following and the follow up questions. On the day of the lab pupils were asked to pair up and take turns in completing the techniques and filming each other with their mobile phone. To save time, the pupils were directed to particular aspects of the procedure to be filmed rather than simply filming the whole process (Supporting Information). Once the procedure was completed pupils were asked to watch their video and comment. They were also asked to view and comment on their partner's video. To conclude the activity pupils had calculations and questions regarding the procedure and techniques and then were asked to reflect upon the whole experience and fill in a simple questionnaire (activity feedback sheet) about how they felt this approach had impacted their learning.

Badges were created in a Credly account[14] using the school e-mail address of a teacher involved so that the badge and criteria associated with that badge could be accessed by pupils from their school e-mail address. This meant that the school would thus have access to the information as evidence in the case of any future query. Pupils did not share their videos but had them on their own phone to review with their lab partner. Pupils were instructed to use the phone of the experimenter to film them, so that the video remained in the possession of the individual student.

The surveys were given to the pupils as part of a task booklet, and successful completion of the task included completing the survey. It was mandatory, and some incomplete pieces of work were returned to ensure completion. The surveys used a 5-point Likert scale, and are an attempt to glean some information on how the activity was perceived. These responses, along with observation data, are used to illustrate how the activity worked in practice. Ethical approval was obtained from school leadership regarding the use of surveys in line with the expected practice.

Three procedures were used, giving pupils the opportunity to gain three badges: a standard solution badge, a volumetric pipet badge, and a titration badge (Figure 1).

Figure 1. Pictures of badges awarded to pupils on successful demonstration of competency in a named technique (preparing a standard solution, volumetric pipetting, and titrations).

RESULTS

Activity 1: Preparing a Standard Solution

Pupils were provided with a link to an exemplar video[15] and instructed to complete a prelaboratory quiz in preparation for this activity. In class, they were asked to prepare a standard solution of sodium carbonate. In order to emphasize the need

Table 1. Comparison of Students' Feedback on the Three Activities

Survey Statements for Response	Student Ratings[a] for the Statements by Activity, %[b] (N = 39)								
	Strongly Agree			Agree			Neither Agree nor Disagree		
	SS[c]	VP[d]	T[e]	SS[c]	VP[d]	T[e]	SS[c]	VP[d]	T[e]
I watched the video before the lesson.	50	80	70	50	20	20	0	0	0
The quiz made me think more about the technique.	47	50	40	50	50	50	3	0	0
I felt more prepared before beginning the task than when there are no prelab tasks.	50	40	40	37	57	57	10	10	0
I tried to explain and justify the steps as I did them.	50	50	50	40	50	40	10	0	0
Watching my video helped me review my technique.	10	10	10	80	80	77	10	10	3
I feel I have a better understanding of this technique because of the badging process.	12	20	20	80	70	70	8	10	0
I found this a useful way to develop my lab skill.	17	17	17	80	80	70	3	3	3
I found this a useful way to develop my understanding of this technique.	53	60	60	37	30	27	10	10	3

[a] The statement "I felt more prepared before beginning the task than when there are no pre-lab tasks" garnered a "Disagree" response of 3% for each of the activities (SS, VP, T). All other responses for "Disagree" and "Strongly Disagree" are 0%. [b] Responses for each statement do not all total 100% because three students did not complete this form. [c] SS indicates the standard solutions activity. [d] VP indicates the volumetric pipetting activity. [e] T indicates the titrations activity.

to understand why each step in the process is required, pupils were asked to describe what they were doing at each stage during filming:

- Enhancing the process of solution by stirring the solution with a clean glass rod
- Ensuring that all the solid has dissolved in water in the beaker before they pour the solution into the volumetric flask
- Ensuring all the solute is transferred through washing equipment
- Raising the funnel while adding solvent
- Adding water using a dropper pipet so that the bottom of the meniscus is exactly level with the mark on the flask when viewed against a white background

The pupils had been asked about these points in the prelaboratory questions as well as why the flask containing the solution must be inverted several times and what the consequences to the concentration of the final solution would be if these steps had not been included. After recording, pupils would review the recorded video and make comments, as well as hear their peer's feedback, on the review sheet provided (Supporting Information).

In the classroom, pupils began the process hesitantly and needed some encouragement. Two pupils hadn't watched the video and were directed to watch it before being allowed to begin. Some mistakes that were observed included producing solutions that were cloudy and overfilling the volumetric flask above the line. These were used to prompt discussion in class: pupils were asked why the solution could not be cloudy, and there was a lot of focus on using a transfer pipet and reading the meniscus correctly. The latter point was a noted outcome of the class.

Pupils were asked about the process both using the survey and open text comments. Responses to the survey (Table 1) indicated that there was general agreement that the video help pupils prepare for the technique and that they had a better understanding of the technique. Open responses from pupils indicate the following: (a) The video helped to build confidence as they were able to watch the video and revise again before lesson. (b) They understood specific aspects of the technique (the process of ensuring all solid had completely dissolved before transferring to the volumetric flask was highlighted by one student). (c) There was a general feeling that the approach was one that benefited their practical skills. Pupils also indicated that presenting was difficult and that they felt it took practice to make their demonstration "more useful".

Activity 2: Volumetric Pipetting

Pupils were again provided with a link to an exemplar video for this technique,[16] and asked to complete prelab questions. This task required pupils to carry out an accurate dilution of a vinegar solution as if they were going to prepare it for titration. A titration was not carried out in this activity as the focus is on volumetric pipet skills, but the process was intended to prepare students for the sulfuric acid/sodium carbonate titration in the next activity. The pupils had to accurately dilute the vinegar using a 25 cm^3 pipet and a 250 cm^3 volumetric flask as if to prepare for a titration with sodium hydroxide. Vinegar is chosen as it aligns with outcomes in the OCR specifications regarding weak acids, but the focus was on the skill of using a pipet safely and accurately. The task also enabled the pupils to use a volumetric flask again, and this built on activity 1. Other points pupils were asked to include in their discussion during filming included the following:

- How to attach the pump, draw solution, remove the pump, and drain down to the mark
- Transferring and the importance of patience when draining the pipet
- Touching the tip to the surface and the residual drop

In the classroom, emphasis was placed on understanding why and how the pipet is used. Pupils would have had a little experience from earlier school work, so this session focused more on emphasizing and explaining the rationale for correct technique. Some errors that were observed and discussed were the submerging of the pipet into solution, and not holding pipets vertically. In this second activity a competitive atmosphere developed between individuals working together to see who was better or who could find more to correct about each other's technique. The environment was an active learning experience with full student participation: all pupils were required to be active and have their activity recorded.

Student comments on this activity again pointed to the sense of being able to prepare for the classwork, but also in this case they identified points that they were unsure of, which they were able to follow up on in class. One student commented that the approach helped to prompt thought about the procedure itself rather than just getting the right answer. The emerging concepts of analytical chemistry were also evident, with pupils being able to explain the use of pipets instead of cylinders for transferring liquids. However, the prelab video demonstrated two different pipet filler types, and this did lead to some confusion, as they did not know which one they would use in class.

Activity 3: Titrations

Pupils were provided with a link to an exemplar video for this technique[17] and asked to complete prelaboratory questions. This task requires pupils to carry out an acid−base titration using a standard solution of sodium carbonate to find the concentration of a sulfuric acid solution, using methyl orange indicator. The pupils were asked to first make their standard solution and then begin filming specific sections (to save time) of the titration procedure as indicated on their instruction sheet. The pupils were given the opportunity to demonstrate their ability to use a pipet before discussing why only a few drops of indicator are added and why a white tile is set below the conical flask.

In the classroom, there was some initial discussion about indicators. Pupils have little experience at this stage of indicators, so this was used to introduce that as a learning point. Many pupils thought that because the sulfuric acid was in a volumetric flask it must be a standard solution rather than the sodium carbonate which suggests that the nature of a standard solution and the purpose of a volumetric flask needed to be reinforced. Setting up and using a buret was a challenge with complaints of there being too many things to remember and most aimed to begin from the initial value zero (the video recommends starting at a point below the zero line to avoid introducing error). Reading the buret to 2 decimal places of which the second place is a 0 or 5 was well rehearsed. Pupils struggled with identifying the end point and using the wash bottle to help rinse the tip of the buret. However, in this case their ability to discuss what they should be doing and why was often superior to their technical skills. An understanding of the procedure had clearly been developed before embarking on the practical experience. Having watched the exemplar video fewer pupils required scaffolding to complete the calculation.

Student comments on this activity mirrored previous ones. In this case the time constraints usually imposed on titration work prompted one student to comment that preparation in advance made more time available for practical work.

Issuing of Badges

For each of the activities, the protocol of determining competency and issuing of badges was the same. As the practical work was being conducted and filmed by students, the teacher circulated with the observation criteria and made a note as to whether or not a student was successful. This follows the normal practice for practical assessment in school. However, the students also (for the first time) had the opportunity to review their own practice and that of their partner. Once students were satisfied with their technique after reviewing the video, they could show it to the teacher (or demonstrate live to the teacher) who kept a record of work submitted and performance in lab and until all aspects were complete. Each badge had specific criteria (Supporting Information) that needed to be met before being issued. As the activities were iterative, students could use second and third laboratory sessions to retry aspects on preparation of standard solution and volumetric titration if they did not achieve them first time around. In our trial, we used the final activity (sodium carbonate/sulfuric acid titration) to judge four students for the pipet skill. This meant that all students had the opportunity to rehearse and achieve the technical aspects required, and all students received badges.

■ DISCUSSION

These activities are designed around a framework of providing videos in advance for pupils to study an exemplar approach to experimental techniques, in-class work focusing on demonstration and explanation of technique while being videoed, and peer and teacher review of videos to discuss issues arising out of the demonstration. The intention was that pupils could prepare for an activity in advance, leaving time during the lesson to tease out understanding.[18] Therefore, this framework aims to maximize time for discussion and dialogue, in order to develop pupils' oracy. The process of watching an exemplar video followed by prelab questions proved to be an important tool in developing understanding. The two teachers involved reported that pupils acted in a more assured and purposeful manner. Shifting the focus away from completing the experiment as simply the means of generating a result, and toward identifying particular techniques within the procedure, enabled pupils to think about what they were doing and how, rather than race through to get the final result. However, pupils lacked the confidence and the vocabulary to clearly describe what they were doing and why they were doing it. The need to develop oracy skills to both improve communication and link ideas and to promote metacognition was very apparent. However, the questions from pupils that followed the lab were generally answered to a much higher standard than they have been previously without the additional preparation. This highlights the different layers of understanding that can be obtained by this process in the same lesson time frame as conducting the titration in a conventional manner.

The tasks had been carefully chosen so that skills were revisited and practiced. While instructors watched the pupils work and listened to their commentaries, progress in this regard was evident. A number of pupils commented on how much more confident and knowledgeable they felt about carrying out a titration than they had previously, and that they had gained an understanding of why the technique is used.

All three tasks were completed within a week, which in hindsight was counterproductive. The task demand was too great leaving the pupils feeling overwhelmed with work to complete, and as a result, the latter tasks lacked the deeper thought and reflection that the badging process was designed to foster.

The pupils were enthusiastic about gaining digital badges but had no previous knowledge nor experience of them. They reported that the concept of a digital badge as a means of demonstrating skills or experience could be very useful but were unsure of how or when they might be used. However, it was observed that the prospect of being awarded a digital badge incentivized them to do well and to give a good demonstration, creating an element of competition in the class.

The teachers involved reported that this process provides a useful way of developing technical skills in a time efficient manner, and exemplar videos offer a powerful tool for developing thinking and understanding of the concepts behind a practical. This elevates the importance of practical work for the pupils. Furthermore, the videos themselves can be employed as revision tools to aid exam study, as pupils may be asked about techniques in their A level exam.

Three months after these activities, students were asked to complete iodometry practical work, and teachers involved reported that students had much mroe confidence with setting up and using the equipment than observed in previous classes. The students used pipets to dilute the bleach solution without hesitation and were confident in using the buret. Our future work intends to explore this effect of retention of practical procedure protocols as a result of our exemplar (peer-assessment protocol) digital badge framework.

■ CONCLUSION

Digital badges are awarded on the basis of demonstrated competency in a particular skill, and this report describes the framework used in a high school setting for issuing digital badges in three laboratory skills: preparing a standard solution, volumetric pipetting, and performing titrations. The framework involved requiring pupils to prepare for the technique by providing exemplar videos of the technique in advance. In class, pupils were asked to demonstrate proficiency in the techniques while being recorded on a video. Once competency was demonstrated, students were awarded a digital badge for that technique. As part of their demonstration, they had to narrate their approach, and this, along with subsequent discussions that emerged in reviewing videos with peer and teachers, meant that there was a much greater extent of conversation about the techniques than there would have been as compared to the traditional approach of just asking pupils to complete a laboratory activity. We believe this approach has potential for those looking to incorporate practical activities and/or increase the level of dialogue with their pupils, with a consequent impact on developing oracy skills.

■ ASSOCIATED CONTENT

Ⓢ Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.7b00175.

> Peer review sheets for each of the three activities and criteria for each badge incorporated into the badge metadata (PDF, DOCX)

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Notes

The authors declare no competing financial interest.

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Chapter 2: A novel practical pedagogy for terminal assessment.

Paper 2	Hennah, N. (2019). A novel practical pedagogy for terminal assessment. *Chemistry Education Research and Practice*, 20(1), 95–106.	
Author's contribution	A single author publication detailing work designed and carried out by the author alone. Manuscript proofread by M.K. Seery	
Other impacts	**Citations (Google scholar)**	**Altmetric**
Featured in RSC *Education* in Chemistry magazine. Poster presented at Methods in Educational research 2017	7	22

What circumstances led to Paper 2?

As a trainee teacher I was introduced to Piaget's (1977) personal constructivist view of learning. Piaget theorised that knowledge is actively constructed by learners in response to interactions with environmental stimuli. Furthermore, learners bring knowledge acquired from previous experiences into the classroom or prior knowledge, which influences what new or modified knowledge they can build from the learning experience (Bates 2015).

Piaget also perceived the role of logic-like operations in human cognition and viewed knowledge as a symbolic mental construct or schema (Bruner 1997). To Piaget a schema is a pattern of learning which links ideas, perceptions, and actions to make sense of the world. From this, I conceived that learning chemistry is a process of changing schemata so that the student's worldview is aligned with that of science.

From a constructivist perspective, hands-on practical work affords students the opportunity to build knowledge and skills. The digital badge protocol in Paper 1, Chapter 1 (summarised in Figure 1.2), can be broken down into three instructional strategies designed to facilitate this process.

Pre-laboratory preparation is the first strategy, it extends the time available to students to engage with the hands-on activity. As students must watch a video that details the equipment and procedure before the lesson, they begin the task with prior knowledge of the equipment and procedures.

The second strategy is the production of a verbal report (Van Someren *et al*., 1994) of what they are doing and why, whilst performing specific tasks within the procedure. Producing a verbal report is an active process in which the learner must unravel complex thoughts to produce coherent verbalised ideas (Ericsson & Simon 1993).

The third strategy is providing feedback on student's performance of the hands-on task and verbal report by recording and reviewing the recorded task. Feedback has a powerful influence on learning and achievement which may be positive or negative (Hattie & Timperley 2007). Here, possible negative repercussions are mitigated by providing the students with the opportunity to repeat the task until the required standard is met. Thus, this strategy is also consistent with the mastery learning model (Bloom 1968) in which learners master the task before moving on to the next topic.

Although the strategies in the badging process described in Paper 1, Chapter, are "evidence-based" (Kvernbekk 2016), science teaching colleagues and I, value empirical evidence that is supported by statistical measures. And, in a climate of education accountability, championing new pedagogy requires data that indicates an increase in exam or exam style question attainment.

My hypothesis was that the badging protocol would increase students' attainment in practical themed exam style questions and so I designed the study detailed in Paper 2. The primary aim of this study was to design and implement a novel pedagogy for the preparation and delivery of a practical episode involving students aged 14–15 years old, and to address the following research questions:

1. Does the novel pedagogy affect the procedure exam question attainment of students aged 14–15 years old compared to the attainment of their traditionally taught peers?

2. Does the novel pedagogy affect student retention of practical procedures?

So, what are the outcomes of the research detailed in Paper 2?

The novel pedagogy described in Paper 2 was informed by the digital badge protocol discussed in Paper 1, Chapter 1 (referred to as the Seery protocol in Paper 2) and combines pre-laboratory preparation and employs oracy to promote thinking during practical work. In addition, a prompt slide had been introduced to help structure student-student dialogue as they carried out each stage of the titration protocol and to support the development of their oracy skills.

The research adopted a quasi-experimental design and employed mixed methods. Quantitative data based on student attainment scores from tests given under exam conditions were collected and affective data were collected through student surveys which used a 5-point Likert scale to garner information on how the activity was perceived.

The average student score was 2 (agree) when asked if the novel pedagogy helped them develop their understanding of the technique and its purpose and when asked if they felt it helped to develop their lab skills. This aligns with the attainment data which revealed a statistically significant higher attainment in practical themed exam question for the intervention group compared to the control group when tested ten weeks after the teaching episode.

Philosophical impact

A paradigm is a series of related philosophical assumptions made by researchers concerning how phenomena are viewed, and which methods should be employed to study them (Waring 2012). "When researchers operate from different frameworks, results will not be readily interpretable by or meaningful to each other" (Patton 2002, p. 134), so the paradigm employed by a researcher must be made clear before the validity of the outcomes can be determined.

Prior to embarking on the research detailed in Paper 2, my ontological and epistemological assumptions aligned with my scientific training. I assumed that there was a single objective reality that can be observed through science, and that knowledge can be obtained using reliable and valid measurement tools (Snape & Spencer 2003). However, education is a social science which may challenge these assumptions.

Reflexivity is a form of critical thinking that seeks to articulate the specific personal, social, and theoretical influences, that shape the research, so that the knowledge produced can be understood (Lazard & McAvoy 2020). Using reflexivity, I identified my implicit belief that the social and psychological world can be studied in the same way as the natural world, which is consistent with positivism (Lodico *et al.,* 2010). Within a positivist paradigm, pedagogy as an example, may be studied using variables to understand how these variables are related to each other in the real world.

Furthermore, I regarded empirical evidence more highly than other data which resulted in my deficit view of affective data. From a positivist viewpoint, knowledge is developed objectively and so the importance of an individual's experiences and views are less important or may be dismissed (Crotty 1998). Through a positivist paradigm, I perceived the need to generate attainment data which led to both the quasi-experimental methodology (Campbell & Stanley 1963), and the criteria for evaluating the research described in Paper 2.

I had theorised that the novel pedagogy would result in a greater attainment than that of the traditional pedagogy. A causal relationship was not identified but, a statistically significant increase in retention and positive affective data were reported. These outcomes forced me to reconsider my assumptions. My ontological position shifted to recognise that humans do not know reality, but we interpret measures used to explore it. Structural realism understands that a real world exists independent of human experience which is described by scientific theories (Worrall 1989).

Seeking to understand my ontological position also necessitated me to reconsider knowledge, what it is and how we can acquire it. I had assumed that people could come to know the world as it really is through science which Crotty (1998) describes as an objectivist epistemology.

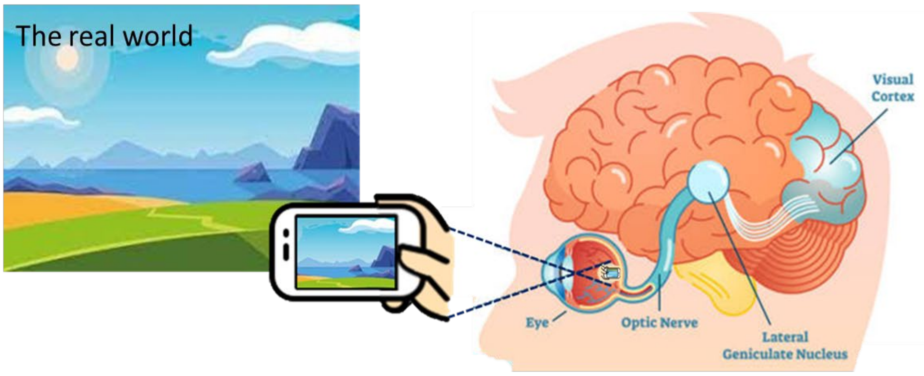
By interrogating this assumption, I recognised that accepting an objective truth denied human interpretation. As illustrated in Figure 2.1, we use the methods and tools of science to detect reality. However, the data generated must then enter the human brain to become known. All observation is made from a point of view which is shaped by our understanding (Popper & Bartley 1985), and so knowledge must be subjective. I recognise now that there is an observable world constructed by human experience and a world independent of our perceptions. The unobservable world produces the observable events which people seek to understand through theories and methods, and that our knowledge is dependent on the theories and methods we use to explore its nature (Moon & Blackman 2014)

Positivist Ontology Paper 1

A real world exists independent of human experience which is observed and described by scientific theories.

Post-positivist Ontology Paper 2

A real world exists which can only be known imperfectly. because scientific theories are derived from scientific observations which involve error.



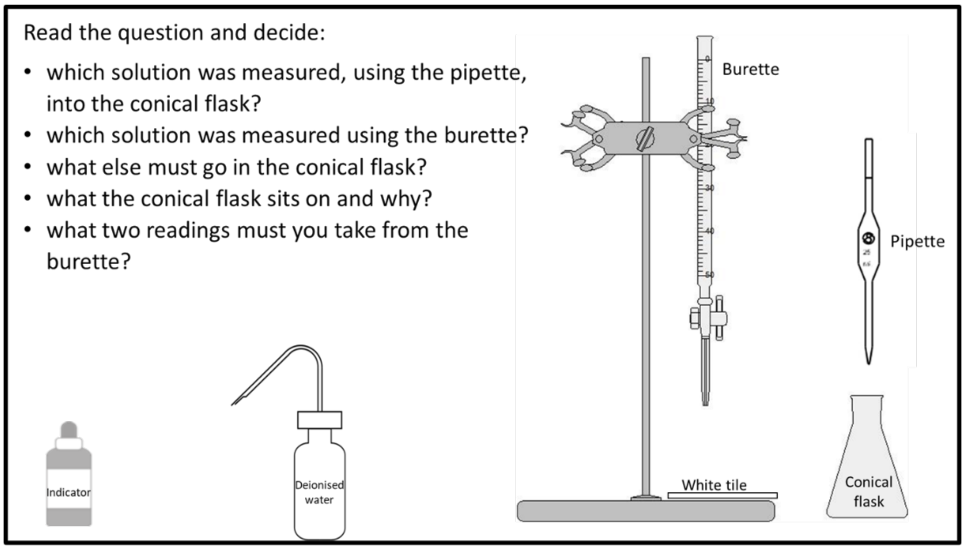
Constructivist Ontology Papers 3 and 4

A real world exists which is known imperfectly due to error and the subjective nature of knowledge construction. The are multiple subjective realities constructed by and between humans within the real world.

Figure 2.1, an illustration of how my worldview has developed as I have engaged with the research process (image from Vecteezy.com).

My teaching experience has shown that students need to be guided by direct instruction not left to discover meaning, which is supported by Kirschner, Sweller, and Clark (2006). This suggest that learning is influenced by other people necessitating a social and collaborative understanding of cognitive constructivism. Thus, I have supplanted personal constructivism (Piaget 1977) with social constructivism (Vygotsky & Cole 1978).

In Paper 2, my adoption of a social constructivist paradigm is evidenced by replacing written laboratory instructions with a prompt slide. The prompt slide, Figure 2.2, encourages students to recall and discuss the titration method detailed in the pre-laboratory preparation video. In addition, listening to these student discussions affords the opportunity of providing immediate feedback to work towards mastery of the task.



Read the question and decide:

- which solution was measured, using the pipette, into the conical flask?
- which solution was measured using the burette?
- what else must go in the conical flask?
- what the conical flask sits on and why?
- what two readings must you take from the burette?

Figure 2.2, the prompt slide which replaced a written method. The slide was designed to encourage students to retrieve and discuss the procedure described in the exemplar video as they carry out the same practical task.

What now for my professional practice?

The National Curriculum for science identifies that the quality and variety of language heard and spoken by students are key factors in developing disciplinary literacy in science. The students detailed in both Paper 1, Chapter 1 and Paper 2, Chapter 2 although different ages, struggled to produce a verbal report of their procedure. Although the prompt slide helped students with what they needed to discuss, they struggled with listening to each other, considering each other's ideas and turn taking which suggests that support for both the content and structure of discussion would be beneficial.

I reasoned that if I could help my students to articulate the procedure, this in turn could improve exam attainment as 'reading and writing float on a sea of talk' (Britton 1970, p. 164) or as Osborne

(2002) explains “it is impossible to build understanding of science without exploring how the multiple languages of science are used to construct meaning’’ (p. 206). It is with this understanding that I sought to develop oracy as a tool for learning and teaching chemistry.

As previously described, task analysis breaks down a complex task into smaller more manageable chunks, which is the effect that this practice-oriented research has had on my understanding of learning through practical work. As summarised in Figure 2.3, I now conceive that practical work can be deconstructed into a net made up of factors that influence the learning that takes place.

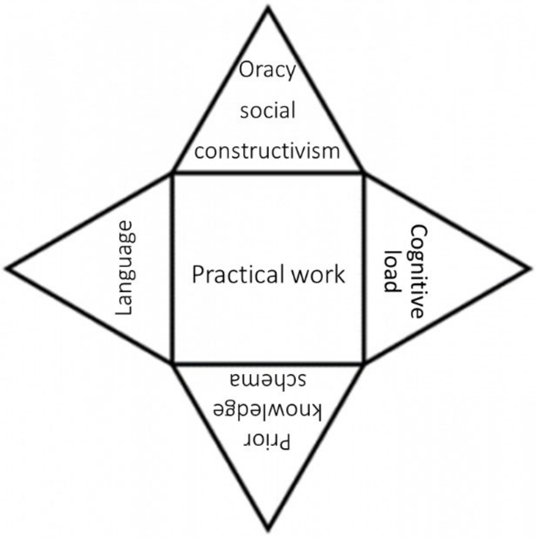


Figure 2.3 uses a net to illustrate to deconstructed practical task. If practical work is conceived as a square based pyramid, the faces are formed by factors that I now perceive as shaping learning through practical work.

When planning practical work for my students I now seek to provide pre-laboratory preparation which makes the purpose of the practical task clear, develops students’ prior knowledge and aims to reduce the cognitive load imposed by the task. I also aim to identify problematic vocabulary and allow time for discussion of the pre-laboratory exemplar video to gauge student understanding, and I have increased the lesson time reserved for whole-class discussion and interpretation of the results which is summarised in Figure 2.4.

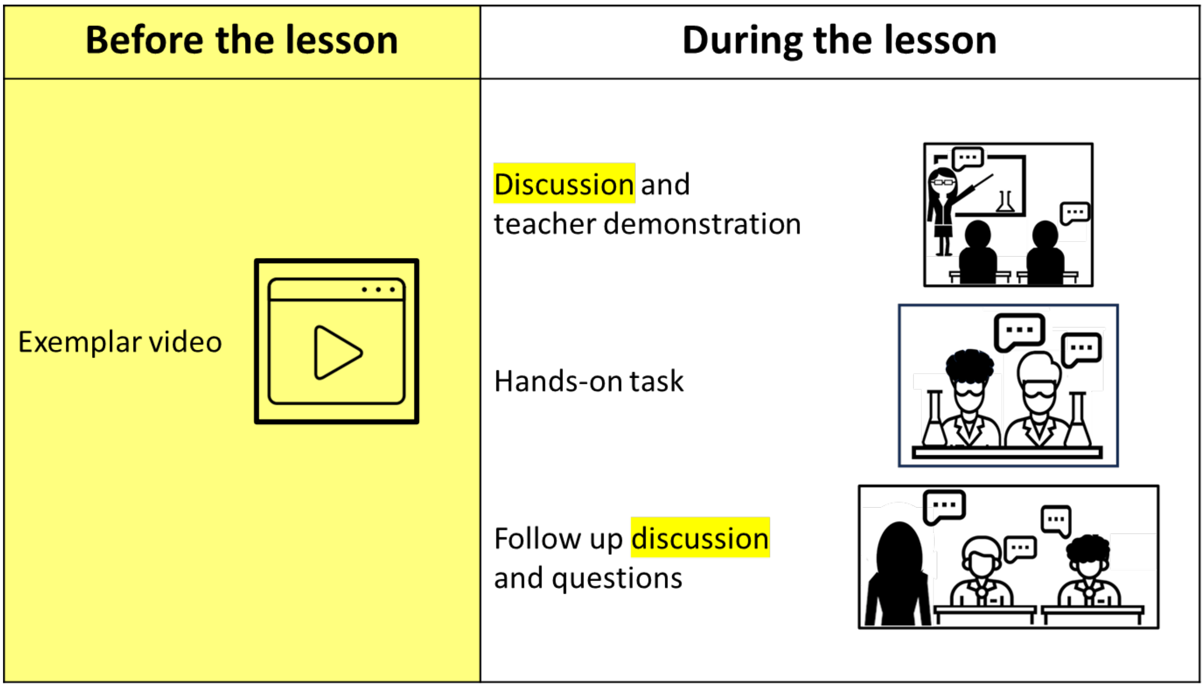


Figure 2.4 summarises my approach to GCSE practical activities following the work described in Paper 2. The modifications to my practice are coloured yellow and demonstrate that I have adopted pre-laboratory preparation using an exemplar video and placed greater emphasis on discussion which includes a focus on problematic vocabulary.

Other professional impacts

In 2018, I completed the inaugural Oracy Leader programme supported by Voice 21 and Oracy Cambridge, the only chemistry/science teacher to do so.

2018 RSC Schools Education Award Winner, awarded for the development and promotion of the importance of language and literacy approaches in Chemistry education practical work.

I was also invited to join the RSC Curriculum and Assessment Working Group, and I began studying for a Master of Education (Applied Linguistics) with The Open University at this time.

Other professional impacts	Audience
Presented and resources Oracy and reading in science workshop ASE conference 2018	International event for science educators
School wide oracy audit and recommendations February -April 2018	Curriculum team leaders and senior staff
Invited presenter at Voice 21 Oracy in Maths and Science Focus Day June 2018	National training event for teachers of science and maths
Wrote, presented, and resourced RSC Literacy event June 2018	Regional teachers of chemistry/science
Oracy in the classroom Teacher training July 2018	Teachers representing every department across the school
Target Talk, Royal Society of Chemistry online poster competition, 2018	International chemistry education researchers
Voice 21 and Oracy Cambridge Oracy Leader programme and Practical Talk, poster presentation 2018	Fellow oracy leaders, Voice 21, and the head of the English-Speaking Union
Hennah, N. Constructive conversations with talk triplets *Education in Chemistry* [online]10 May 2018. Available at https://edu.rsc.org/ideas/constructive-conversations-with-talk-triplets/3009003.article	Education in Chemistry magazine readers
Hennah, N. Free online CPD: CERGinars, *Education in Chemistry* [online] 31 May 2018. Available at https://edu.rsc.org/review/free-online-cpd-cerginars/3009087.article	Education in Chemistry magazine readers
Hennah, N. Help students connect observations to theory *Education in Chemistry* [online] 5 October 2018. Available at https://edu.rsc.org/ideas/help-students-connect-observations-to-theory/3009420.article	Education in Chemistry magazine readers
Hennah, N. How to teach acids, bases and salts *Education in Chemistry* [online] 10 October 2018. Available at https://edu.rsc.org/cpd/acids-bases-and-salts/3009612.article	Education in Chemistry magazine readers

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A novel practical pedagogy for terminal assessment†

Naomi Hennah

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The present paper reports upon the design and implementation of a novel practical work pedagogy that is shown to increase students' retention of practical procedures. The chemistry exams, for 15 to 16-year olds in England, will be assessed entirely through terminal examination questions from 2018. Longer term retention of learning is critical if these students are to minimise any discrepancy in attainment that may arise from following curricula with a coursework component. The novel design, underpinned by Cognitive Load Theory and Social Constructivism, involves pre-laboratory preparation and employs oracy to promote thinking during practical work. Three equivalent chemistry groups within the same school undertook neutralisation and crystallisation practical tasks and their practical work exam question attainment data is analysed. The novel pedagogy is trialled as a neutralisation task with one group and affective outcomes are determined through Likert scale activity feedback questionnaire. Attainment data shows a statistically significant higher mark in practical exam question attainment for the intervention compared to the control group when tested ten weeks after the teaching episode.

Introduction

Practical work assessment in school chemistry

That ''Chemistry is necessarily an experimental science; its conclusions are drawn from data, and its principles supported by evidence derived from facts'' (Faraday, 1827, p. B) remains uncontested, but the role, delivery and assessment of practical work are subject to debate. In the UK the requirement for secondary school students to engage in practical work as an integral part of science education, was codified in 1904 (Board of Education, 1904). Practical work is both time consuming and expensive, but its inclusion in assessment criteria justifies its costs, and ensures its retention.

In 1988 the General Certificate of Secondary Education (GCSE) was introduced bringing with it teacher assessed coursework. Coursework aimed to provide a mechanism by which practical skills, in contrast to practical work itself, of a large number of students could be assessed. The National Curriculum for Science allocated a minimum of 20 percent of the total marks to experimental and observational work in the laboratory or its equivalent (Jenkins, 1998). In 2011 coursework was replaced by controlled assessment; coursework could be redrafted resulting in attainment that did not reflect scientific skill, whereas aspects of the controlled assessment were undertaken in exam conditions. Practical skills assessment comprised of two written papers undertaken in exam conditions, enabling large numbers of students to be assessed by their teachers. Controlled assessment accounted for 25 percent of the final GCSE science mark but may have involved as few as two practical episodes. The most recent round of curriculum reform in neighbouring Ireland, Northern Ireland, Scotland and Wales, have all resulted in either in a coursework or controlled assessment component in their 14–16 chemistry exams (Perry, 2013) however, from September 2016 in England, practical skills will be assessed solely based on examination. The exams will contain questions that specifically draw on the experience students have gained from doing practical work (Office of Qualifications and Examinations Regulation (Ofqual), 2015), the exam boards are required to detail the apparatus that students should use and the techniques they should develop, through a minimum of eight practical activities upon which the examination questions are based. Schools are only required to confirm, rather than provide evidence to exam boards, that their students have undertaken the tasks and kept a record of their work. At least fifteen percent of the total marks available in GCSE Chemistry will be dedicated to these exam questions; ''this proportion is large enough to have a significant effect on a student's grade, but not so large as to distort assessment or hinder coverage of other requirements'' (Ofqual, 2015, p. 2). A further twenty percent of the total marks available in GCSE Chemistry have been allocated to assessing mathematical skills.

Practical work in GCSE lessons

Secondary School practical lessons often form a part of a teaching sequence, building upon students' prior knowledge

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and skills. This sequence is drawn to the students' attention through learning objectives and teacher instruction, ''setting the scene'' (Wellington, 2000, p. 150). To quote Millar (2009, p. 5) ''It would be unreasonable to expect durable long-term learning of a scientific idea or concept to result from a single, relatively brief, practical activity. Learning, where it occurs, is likely to result from a sequence of lessons which involve activities of various kinds, including some carefully planned practical activities at appropriate points.''

The choice of the practical activity to be undertaken and where it occurs in a teaching sequence may be dictated by a departmentally produced scheme of work (Abrahams, 2005); exam boards in England such as the Assessment and Qualification Alliance (AQA) provide an exam specification and suggested schemes of work which include practical activities (http://www.aqa.org.uk/resources/science/gcse/chemistry/teach/schemes-of-work). The Department for Education has specified eight required practical activities to be conducted as part of the curriculum and assessment of GCSE chemistry (AQA, 2017, p. 2) for which exam boards have developed their own suggested activities that ensure the apparatus and technique requirements are met. Again, providing an example from AQA, their suggested activities include the following reminders ''written papers will include questions requiring knowledge gained from carrying out the specified practicals'' (AQA, 2018 front cover) and, ''not having done some of the practicals, despite the school's best efforts, will not stop a student from entering for the GCSE. However, it may affect their grade, because there may be questions in the exams that they won't be able to answer'' (AQA, 2016b, p. 4).

Abrahams and Millar (2008) reported that teachers viewed their responsibility in terms of the delivery of an activity judged to be appropriate by others, a 'foolproof' experiment from which the right answer will emerge as long as the instructions are followed (Kirschner, 1992, p. 278). The procedure is introduced to the students by the teacher using at least one of the following devices; oral instructions that may be supported by written instructions or diagrams on a board or screen; the teacher may demonstrate aspects of the equipment or the procedures or even the entire task before the students begin and there may be a labsheet that dictates the method which may also include a diagram of the apparatus (Millar, 2009). Tiberghien *et al.*, (2001) reported that most teachers use labsheets to direct the students' activities during the practical activity, the teacher may adopt a ''supervisor'' role (Wellington, 2000, p. 150), a ''good'' teacher will then move around the laboratory intervening as required, providing equal attention to groups asking for assistance and those that don't (Hamidu, 2014, p. 84). Classroom studies indicate that teachers and students primarily focus on following the ''recipe'' (Clackson and Wright, 1992, p. 41) and handling an apparatus (Abrahams and Millar, 2008; Hodson, 1993; Lunetta *et al.*, 2007; Tiberghien *et al.*, 2001). Abrahams (2005) observed teachers limiting the time allocated to presentation and explanation of practical work or materials or spending little or no time considering the concepts behind the activity, giving precedence instead to the time available for students to manipulate objects and materials.

What should be improved?

Hodson (1990) described laboratory work as unproductive and confusing as it is often used without clear thought-out purpose. The emphasis on closed ''recipe'' following practical tasks as previously described enable hands-on activity without affording the opportunity for engaging minds. In England the GCSE exam specification explains three reasons for carrying out practical work; firstly, to support and consolidate scientific concepts, secondly to develop investigative skills such as controlling variables and finally to develop practical skills that include taking measurements using specialist equipment (AQA, 2016a, p. 91). It has been argued that the purpose should be more than skill development but also include, in addition to opportunities to develop conceptual understanding, affective aims such as interest and enjoyment (Johnstone and Al-Shuailib, 2001). Abrahams' work (2009) in the affective value of practical work in secondary school science reported that much of the perceived motivation was in fact situational interest that passes as the lesson ends and thus, unlike motivation, it is not necessarily as effective in helping to develop student learning.

Providing students with a set of procedures to follow in a manner akin to a ''cookbook'' (Tobin *et al.*, 1994, p. 51) is common practice among teachers, (Ibrahim *et al.*, 2014), the persistence in use of recipe style activities has been attributed by some teachers as being due the need to provide structure so students can complete the practical task with in the limited time, but Abrahams and Millar (2008) report, in the same study, issues related both to the reading and understanding of such written instructions. One problem with the traditional pedagogy described here is that working memory space becomes overload during laboratory episodes resulting in a lack of space available for cognitive processing (Johnstone and Wham, 1982) the consequence of which is that students adopt the default position of using their written instructions as a ''mind-in-neutral'' recipe (Johnstone, 2006, p. 58) rather than thinking about what they are doing and why.

Psychologists use the theoretical constructs of long-term memory and working memory to describe the functioning of cognitive architecture (Aben, Stapert and Blokland, 2012). Long-memory contains the cognitive structures that make up an individual's knowledge base, schema (Sweller, 1988). The human mind uses schema to organise, retrieve and encode chunks of information, once formed schema tend to be stable over time (Gobet, Lane, and Lloyd-Kelly, 2015). There has been no measure of a limit to the number of schema the long-term memory can hold conversely, the capacity to hold information in the working memory is very limited (Sweller, van Merrienboer and Paas, 1998, Cowan, 2010).

Johnstone (2006) explains that the working memory has two functions, firstly as a temporary store for incoming information and secondly, to process this information. Processing results in an action being taken, a response, and/or the information being transferred into the long-term memory. Processing requires that incoming information interacts with schema retrieved from the long-term memory, if the new information can be fitted to an existing schema it will be transferred into the long-term memory. Fitting new information into an existing schema is an ''active, constructive process'' (Sweller *et al.*, 1998, p. 255) which produces the complex schema. Complex schema built up over time not only hold chunks of related knowledge but can be treated as a single entity by the working memory thus freeing up space for additional information to be processed. The limited capacity of the working memory inhibits complex reasoning involving many new pieces of information thus, it is the existence of prior knowledge held in complex schema that distinguish between a novice and a master (Sweller *et al.*, 1998).

The load placed on working memory, that is the number of new or unfamiliar entities, must be minimised to enable transfer of information into the long-term memory. Instructions and learning opportunities must consider cognitive load when being designed as the information contained in instructional material must first be processed by working memory (de Jong, 2010) before a response can be elicited. Working memory has two processing systems that initially process visual and verbal information independently. Thus, information presented in more than one modality is divided across two of these systems, effectively reducing the cognitive load applied (Kirschner, 2002).

Johnstone (2009), fearful that students could be successful in their laboratory class with very little understanding of what they were doing, suggested a need for both pre-laboratory preparation and assessment for laboratory outcomes as a means of rewarding their efforts. A recent review of work on pre-laboratory preparation (Agustian and Seery, 2017) puts forth a convincing case for the inclusion of pre-laboratory activities that seeks in part to address the issue of cognitive load and offers a framework for the incorporation of pre-laboratory preparation in higher education. The success of pre-laboratory video to prepare students for laboratory work is demonstrated by Schmidt-McCormack *et al.* (2017).

Cooperative learning (also referred to a collaborative learning) has been reported to increase student achievement (Warfa, 2016). Raviv, Cohen and Aflalo, (2017) conducted a small-scale study of collaborative learning in a school laboratory and reported an improvement in skill acquisition and conceptual understanding in addition to positive affective outcomes among the 12 year-old female participants. Transforming group work into a collaborative task requires materials to be modified and activities to be structured so that every member of the group is responsible for contributing to the group work and the groups success (Leikin and Zaslavsky, 1999) Collaborative learning has its foundations in Social Constructivism (Vygotsky, 1934), a learning theory that emphasises the role of language and culture in cognitive development. Knowledge is thought not to be transmitted from one individual to another but co-constructed through social interaction: First, a student learns to adopt the language and symbols used by a more capable other to describe their processes of logical reasoning or conceptualisation, then the student internalises the ideas and perceptions expressed by the more capable other and, lastly these external actions are transformed to become internal to the student. In this way a more capable student provides ''scaffolding'' (Wood *et al.*, 1976, p. 90) until all members of the group are able to complete the task themselves. The more capable other may arise through the structure of the activity, Smith, Hinckley and Volk (1991) for example, divided up the tasks in their activity so that each student in a group was assigned a particular part of a lesson or unit and then, in turn, each student acted as the more capable other, helping the other members of the group learn that section of the material.

Pre-laboratory preparation and assessment for laboratory outcomes. The work of Seery *et al.* (2017) detailed a method that employed exemplar videos, peer- assessment and digital badges to prepare, assess and reward laboratory skill development (referred to here as the Seery Protocol). The Seery Protocol employs a peer observation checklist to guide students as they film each other performing the techniques. Students may opt to reshoot the video as a result of the feedback. Thus, the Seery Protocol incorporates both a mastery learning model; assessment- feedback- repeat (Bloom 1968); Johnstone's model (2009), pre-laboratory preparation and assessment for laboratory outcomes. Furthermore, incorporating digital badges to reward skill development has been shown to motivate learners (Abramovich *et al.*, 2013). A modified version of the Seery Protocol has been previously reported (Hennah and Seery 2017) in which, secondary school students aged 16 to 18 years were required to both watch exemplar videos and answer pre-laboratory questions. The questions had been designed to highlight pertinent techniques or to encourage students to think about why a particular action was required.

Aim of the study

The primary aim of this study was to design and implement a novel pedagogy for the preparation and delivery of a practical episode involving students aged 14–15 years old and to determine its success through student attainment in exam style questions.

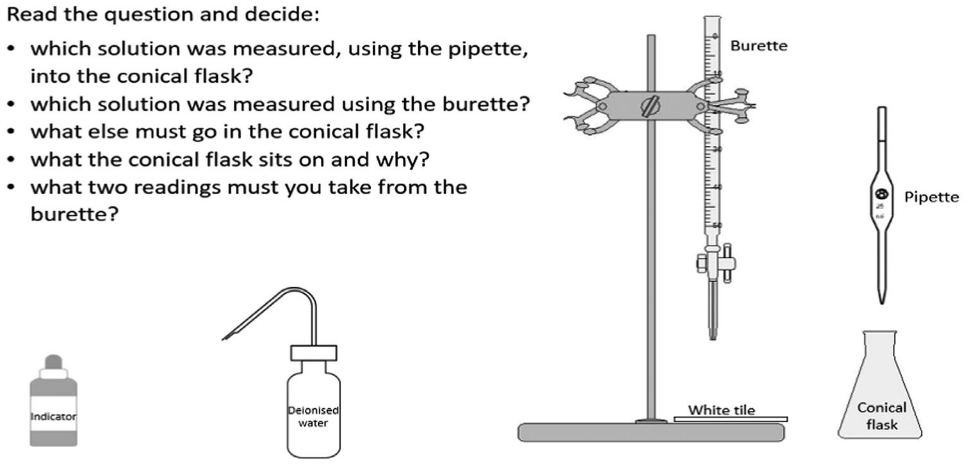
Research questions

1. Does the novel pedagogy affect the procedure exam question attainment of students aged 14 to 15 years compared to the attainment of their traditionally taught peers?

2. Does the novel pedagogy affect student retention of practical procedures?

Designing an alternative pedagogy

The rationale for change is to transform practical work pedagogy from ''hand-on'' into ''hands-on and minds-on'' tasks. The literature presented in this paper reports the positive impact of pre-laboratory preparation on undergraduate teaching laboratory work, these instructional principles will be applied within a Secondary School setting. Success in GCSE Chemistry is determined in totality upon terminal assessment, thus the need to develop practical episodes that enable procedure retention over time is paramount to success.



Read the question and decide:

- which solution was measured, using the pipette, into the conical flask?
- which solution was measured using the burette?
- what else must go in the conical flask?
- what the conical flask sits on and why?
- what two readings must you take from the burette?

Fig. 1 Prompt slide acts as a talking point to support reconstruction of the method through group talk.

To address the concerns about lack of clear purpose (Lewthwaite, 2014), the practical activity analysis inventory (PAAI) was employed (Millar, 2009). The PAAI aims to ensure clarity of both the task objectives, and to identify what the students were intended to gain from them. Here the primary objective for students, carrying their first titration, is to learn how use the equipment correctly. The second objective is to learn how the values obtained become the titres from which the concentration of the analyte may be determined. Thus, the emphasis is placed upon gathering data and how to use that data, linking ''hands-on'' procedure directly to the ''minds-on'' concept of concentration.

Student Task 1 pre-laboratory preparation. The exemplar titration video (Kucharski and Seery, 2016) was selected for use as it provided a clear step-wise introduction to titration and best-practice techniques, although designed for use with undergraduates its implementation of the Seery Protocol with post-16 teaching groups has also been reported by the author as increasing student confidence (Hennah and Seery, 2017). The Seery Protocol has been modified so that in addition to watching the exemplar titration video students will also be required to complete a pre-laboratory question sheet. The questions include images snipped from the exemplar video to direct the students to think about both the procedure and the underlying concepts. Using visual prompts, taken directly from the video, was used as a bridge between the abstract concept in the question and the procedure as a support for students trying to link concepts and practical tasks. Student Task 1 is available in Appendix 1 (ESI†). The students must submit this work before carrying out the practical task to encourage task completion and to provide the opportunity for both written and verbal feedback to clarify understanding.

Prompt slide. The need to simplify laboratory worksheets has long been argued (McDowell and Wadding, 1985; Sweller, 1994) and here a practical prompt slide replaces the written method provided by a labsheet (Fig. 1) for greater simplification. The slide acts as a ''talking point'',‡ a strategy for stimulating students' speaking, listening, thinking (Dawes *et al.*, 2010); a scaffold to support students' social construction of the procedure as a device to support learning (Vygotsky, 1978; Bransford *et al.*, 1999; Mercer, 2013). Replacing written instructions, which have previously been identified as problematic (Abrahams and Millar, 2008), with the prompt slide and verbal discussion provides more than one presentation modality and may help reduce the cognitive demand of the instructions (Kirschner, 2002) freeing working memory to process information and enhance learning (de Jong, 2010).

Student Task 2 collecting data. A second written task is to be completed during the laboratory session, which has been designed to encourage students to recall their pre-laboratory task and to provide scaffolding for recording data and completing the novel titration calculation. In addition, students will receive a peer-assessment observation sheet consistent with the Seery Protocol and lastly a Likert-scale student feedback form to collect affective data (Hennah and Seery, 2017). These materials are available in Appendix 3 (ESI†).

Methodology

Ethical approval was first obtained from the school management to carry out this research. Students were informed about the purpose of the research and given information about what data was being gathered, and that they had the right to withdraw.

The research questions were addressed through quantitative methods based on student attainment scores from tests given under exam conditions. To ensure the test marking was equivalent between groups with different teachers, a marking matrix was used and samples of all the marking were moderated and agreed. Marking was checked prior to moderation and Cohen's kappa (Cohen, 1960) was run to determine the agreement between the judgements $k = 0.769$ (95% CI, 0.564 to 0.975), $p < 0.0005$. Although this agreement is good (Landis and Koch, 1977) it is the moderated marks that have been used.

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‡ Oracy pedagogy employs tools such as ''talking points'' (Lyn Dawes, 2004) to develop and assess students' ability to use spoken language (http://www.educ.cam.ac.uk/research/projects/oracytoolkit/).

Research question 1 attainment data collection

At the end of each school term students' progress is assessed under exam conditions using a short examination paper (approximately 40 minutes) comprised of past exam questions or exam style questions based on the content covered during the term. Each end of term assessment includes a practical work question and where applicable a linked calculation question. Student attainment only in the practical work questions will be collected. Assessment deadlines are set within the school calendar. The teaching content is specified within this calendar thus any modifications to pedagogy cannot result in a requirement for more teaching time. The experimental methods for neutralisation and crystallisation are provided in Appendix 2 (ESI†).

There are three GCSE chemistry exam classes included in this study, control groups C1 and C2 and the test group T, each group has a different teacher but the teaching time, materials and laboratory resources available for the neutralisation (Oxford University Press, 2016) and crystallisation (AQA, 2016c) required practical activities considered in this work, are the same for each group. The presentation of crystallisation practical utilises only traditional pedagogy for all three groups. The control groups C1 and C2 utilise traditional pedagogy whereas, test group T follow the novel neutralisation pedagogy.

Group T attainment data from neutralisation practical exam question will be compared to attainment data from crystallisation practical exam question responses; that is the same group, same teacher but different teaching approaches. The attainment data from the three classes neutralisation practical exam question and crystallisation practical exam question will be compared to make visible variation due to task demand between the crystallisation and neutralisation required practical activities and for random errors arising from teacher and student variations. Titration calculation question attainment data has also been recorded for the three groups.

The baseline comparison. Students are given forecast grades for GCSEs based upon their Key Stage 2 (KS2) results from primary school (age 10 to 11 years). Using each student's KS2 English Reading and Mathematics test attainment scores as a starting point, national transition matrices are used to generate a target grade for the end of Key Stage 4 (KS4) when the GCSE exam is taken (UK Government, 2015). Schools calculate a minimum achievement grade (MAG) for each student for each subject. This is the baseline from which stakeholders are able to judge if a student or a class has been successful.

Three chemistry classes of 31 male students aged between 14 and 15 years old were used in this study. Two of the classes were taught entirely with traditional pedagogy, control 1 (C1) and control 2 (C2), whereas the third, Test (T) were taught the neutralisation procedure using the novel pedagogy. Analysis of student attainment data occurred only if the student had taken part in both practical events and that their exam papers were available for moderation and analysis.

A one-way Anova was conducted to compare the Minimum Attainment Targets (MAG) of the three groups C1 (n = 23), C2 (n = 25) T (n = 26). Normality checks and Levene's test of homogeneity (1960) were carried out and the assumptions were met. There was no statistically significant variance in the mean MAG between the groups [F = 2.314, p = 0.106] Levene's test supports the null hypothesis that group variances are equal.

Research question 2 attainment data collection. The practical exam question data discussed previous is collected at the end of each school term, approximately two weeks following completion of the practical task. The practical exam question attainment data for group T crystallisation (traditional pedagogy) and group T neutralisation were compared using standard z-scores (Lavrakas, 2008). T group students were also given an unannounced test using the same neutralisation and crystallisation procedure questions ten weeks later. Standard z-scores were calculated a for the data collected to compare attainment in procedure exam questions following traditional pedagogy (crystallisation) and the novel pedagogy (neutralisation) and to compare the attainment in these questions following an interval of ten weeks.

Results

Research question 1: does the novel pedagogy affect procedure exam question attainment of students aged 14 to 15 compared to the attainment of their traditionally taught peers?

Group T were provided with the same time and equipment to complete their practical work as the control groups. The same required practical was carried out by all three groups however, group T the students were not provided with a practical task sheet but were required to collaboratively construct their method with a talking point prompt to scaffold their talk. The greatest difference in pedagogy occurred in the level of pre-laboratory preparation as the students were required to watch an exemplar video and complete questions and receive feedback on their answers prior to undertaking the practical work. Attainment scores for each of the groups C1, C2 and T have been plotted as box plots (Fig. 2–4). Attainment scores for a titration calculation question has been included in addition to the crystallisation and neutralisation procedure questions scores as titration calculations are of fundamental importance to determining the success of a titration teaching episode.

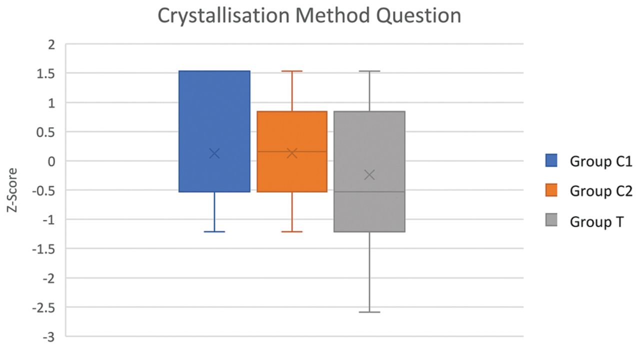

Fig. 2 Box plot of group attainment in crystallisation method question. All groups taught using traditional pedagogy.

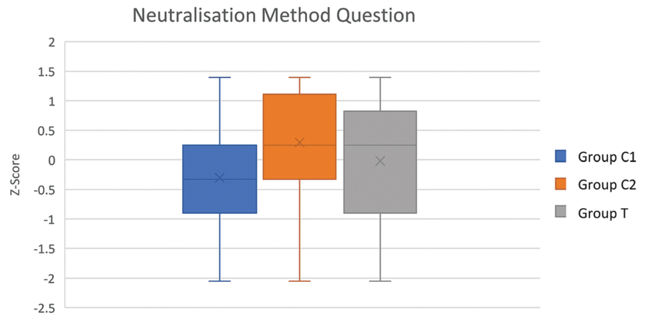

Fig. 3 Box plot of group attainment in neutralisation method question. Control groups C1 and C2 taught using traditional pedagogy whereas the novel pedagogy was used with group T.

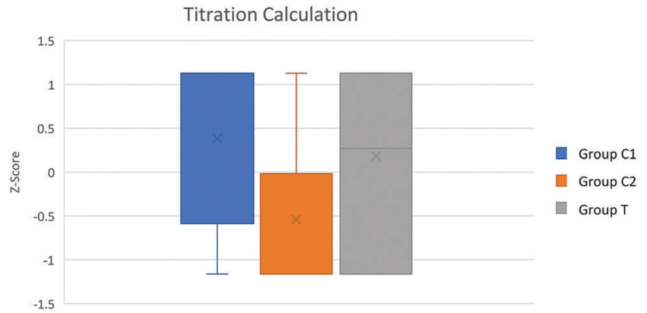

Fig. 4 Box plot of group attainment in titration calculation question. Control groups C1 and C2 taught using traditional pedagogy whereas the novel pedagogy was used with group T.

The two control groups C1 and C2 were taught using the traditional pedagogy only.

ANCOVA analysis for covariance

A one-way ANCOVA was conducted to determine a statistically significant difference between groups C1, C2 and T attainment scores from the crystallisation method (traditional pedagogy), neutralisation method (T Group novel pedagogy) and the titration calculation questions. Levene's test and normality checks were carried out and the assumptions met for each of the three data sets.

There was a statistically significant difference $F(2,70) = 4.13$ $p = 0.046$ between the attainment scores, controlling for class average MAG, for the crystallisation question. The Group mean score (adjusted) were calculated to be C1 = 3.838, C2 = 3.972, T = 3.517, random errors arising from teacher difference may have contributed to this result as the traditional pedagogy had been implemented for the crystallisation practical work with all three groups.

A statistically significant difference between groups C1, C2 and T attainment in the neutralisation method question $F(2,70) = 3.39$ $p = 0.039$ and for titration calculation question attainment score, $F(2,70) = 6.51$ $p = 0.003$ controlling for class average MAG in both analyses. The significant differences in neutralisation and titration attainment result from control group difference, random errors arising from teacher difference may have contributed to this variance.

Research question 2: does the novel pedagogy affect student retention of practical procedures?

Data from the end of term exams, approximately two weeks following the teaching episodes, were collected and the mean scores calculated (Fig. 5), although the Group T mean score is higher following the novel (neutralisation) pedagogy than for the traditional (crystallisation) pedagogy, analysis of z-scores ($F_{1,26} = 1.08$, $p = 0.42$) revealed no statistically significant difference. Group T students were given an unannounced test using the same neutralisation and crystallisation procedure questions ten weeks later, attainment scores for both neutralisation and crystallisation had fallen, but the means score for the traditional pedagogy are lower (Fig. 5). Analysis of z-scores for this data suggests that there is a statistically significant difference in attainment following the novel pedagogy after ten weeks compared to attainment following the traditional pedagogy ($F_{1,26} = 2.28$, $p = 0.02$).

Furthermore analysis of the difference between attainment after 2 weeks compared to 10 weeks revealed a statistically significant difference for the traditional pedagogy, Z crystallisation scores − Z 10 week crystallisation score $t(25) = 4.99$ $p = 0.00$ but not for the novel pedagogy Z neutralisation scores − Z 10 week neutralisation score $t(25) = 1.83$ $p = 0.08$.

The traditional pedagogy, in this small-scale study, has resulted in students performing better in procedure exam questions after ten weeks than they performed in procedure exam questions

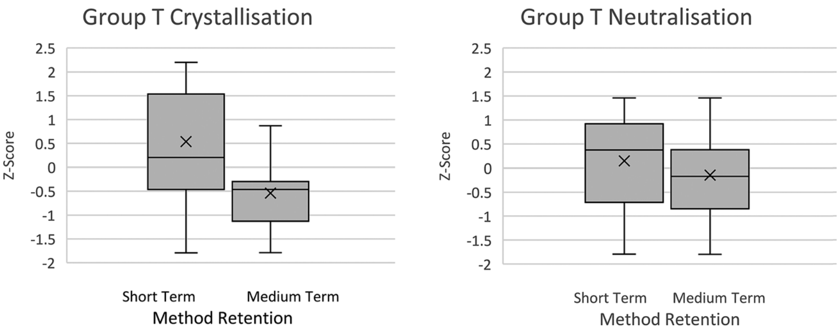

Fig. 5 Procedural exam style question attainment following traditional (crystallisation) and novel (neutralisation) pedagogies. Students were tested two weeks after the practical activity (short term) and then approximately ten weeks later (medium term). The box plots indicate that group T have retained the neutralisation method information better than the crystallisation information.

following traditional pedagogy after the same time interval. There is also a statistically significant difference in their procedure exam style question attainment after ten weeks following the novel pedagogy than there was following the traditional pedagogy. This data indicates that the novel pedagogy is having a positive impact on the students' performance in procedural exam questions after ten weeks.

Implementation of the novel pedagogy

As discussed previously, 15 percent of the GCSE Chemistry exam marks are allocated to questions requiring knowledge gained from carrying out the eight specified practical activities. Time constraints imposed by a broad curriculum and limited teaching time dictate that practical work must be effective in developing both the procedural knowledge and knowledge of the underlying concepts. Research literature has repeatedly found that practical work does not offer a significant advantage in developing students' scientific conceptual understanding as measured using pen and paper tests (Abrahams, 2017, p. 404). The novel pedagogy included pre-laboratory tasks explicitly planned (Abrahams and Reiss, 2012) to encourage students to think about what they observe during the pre-laboratory video. In addition to exam question attainment students' responses to pre and post-laboratory task questions were collected (Task 1 and Tasks 2) and affective data from a student questionnaire (activity feedback response).

Activity feedback responses. Attainment data from group T ($n = 31$) were collected, a reliability analysis was carried out on the perceived task values scale comprising 7 items. Cronbach's alpha showed the questionnaire to reach acceptable reliability, $\alpha = 0.97$.

The novel pedagogy required students to watch the pre-laboratory video, complete and submit the Task 1 questions (Appendix 1, ESI†), 30 of the 31 group T students watched the video before the practical episode. This is attributed to both novelty and the necessity of completing and submitting the Task 1 pre-lab questions. Feedback responses expressed as Likert scale averages can be seen in Fig. 6. The students' average response is above 3 (neither agree nor disagree) for all the items except to the question asking whether or not they had narrated their procedure. Narrating the procedure was included in the novel pedagogy to encourage students to justify their actions and in doing so connect their "hands-on" activity with their "minds-on" concepts. How students can be better encouraged to do this is a subject to addressed in future iterations when oracy techniques are more familiar to them. The average student score as 2 (agree) when asked if the novel pedagogy helped them develop their understanding of the technique and its purpose and when asked if they felt it helped to develop their lab skill.

The final open-ended question was predominately left without comment. The three comments left referred specifically the video; the video did not make it clear why titration was carried out in this way; it was hard to understand; the video was confusing because the maths wasn't clear and used different symbols. The exemplar video was selected for its clarity of best practice techniques but had been designed to be used by chemistry undergraduates. It will be interesting to observe in future iterations whether an age and experience appropriate video would result in more positive affective results. Anecdotally, the same individual who reported not having watched the pre-laboratory video also reported three strongly disagree responses.

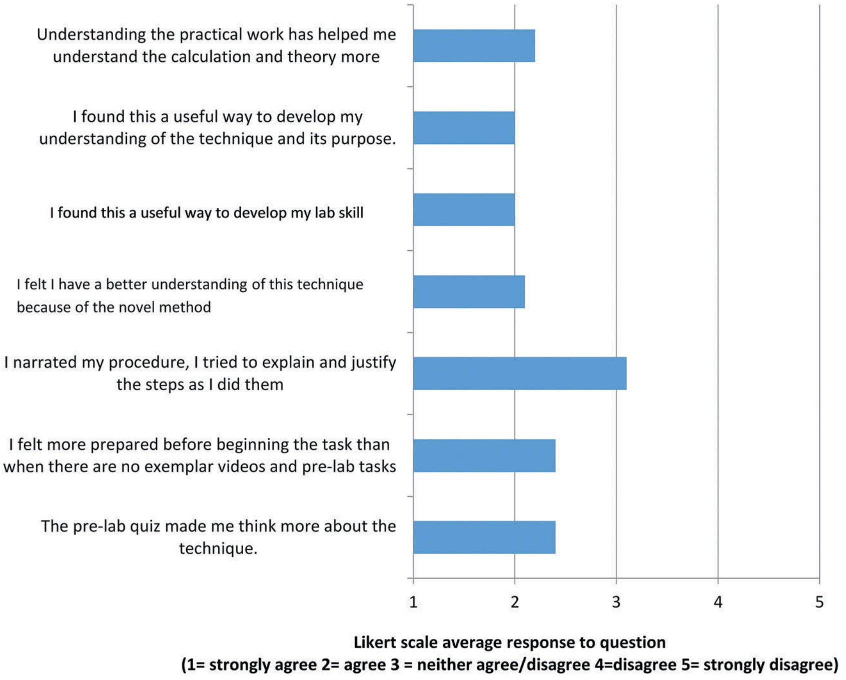

Fig. 6 Group T student questionnaire responses following the novel neutralisation practical episode. The responses have been stated as a class average Likert scale score.

Task 1 pre-laboratory question

All students handed in the task sheet, the extent to which they responded correctly, incorrectly or provided no response has been summarised in Fig. 7. The questions were teacher-marked and whole class verbal feedback verbal feedback was given to the class before the practical episode. The school expectation and practice require students to capture verbal feedback by annotating their work in green pen.

The highest percentages of correct answers are to those questions that require recall from the exemplar video whereas the lowest scores were for questions 8 and 9. Question 8 asks why a pink colour appeared at the top of the flask as the titrant is added but disappeared when the conical flask is swirled, although students realised the solutions were being mixed the majority inferred that the indicator was being mixed in. Question 9 asks why washing the burette tip and conical flask can produce a colour change, most answers inferred that the water was reacting. These misconceptions indicate that the students struggle to link the procedure with the underlying chemical concepts. The results in Fig. 7 suggest that the pre-laboratory materials were preparing the students for the physical processes of the practical episode but did not support linking procedure and conceptual understanding. Question 10 asked students to calculate the titre, testing their understanding of the terminology. Only 60% responded correctly, most incorrect answers gave the end volume indicating that insufficient time had be allocated to rehearsal of titration specific language and as such the terminology acts to increase the cognitive load (Johnstone and Al-Shuailib, 2001). Exam questions require concentration to be calculated most often using the unit moles per cubic decimetre. As question 11 indicates, that the confusion between the units used on glassware and those used in calculations persists.

Prompt slide

The practical work focusses on manipulative skills rather than data generation to reduce the ''noise'' (Millar, 2004, p. 20) in the experiment. The students rehearse the procedure *via* exemplar video, then introduced to the school equipment and how it is set up before carrying out the procedure themselves. Working in groups, students selected and set up the equipment using talk and the prompt slide replicate the method. The students were able to conduct the neutralisation safely and effectively without being issued with a full written method following a detailed demonstration linked to the projected prompt image and the peer assessment checklist. Only one group, comprised of 2 students commented that they did not have a method sheet.

Collaborative learning episodes can be made more effective through training learners to employ language as a tool for collective reasoning, ''Exploratory Talk''. This mode of talk occurs when everyone: listens actively, asks questions, shares relevant information, contributions builds on what has gone before, there is a sense of shared purpose, and the group seeks agreement for joint decisions (Mercer and Littleton, 2009). Although the prompt slide used in this study provided a ''talking point'' the students

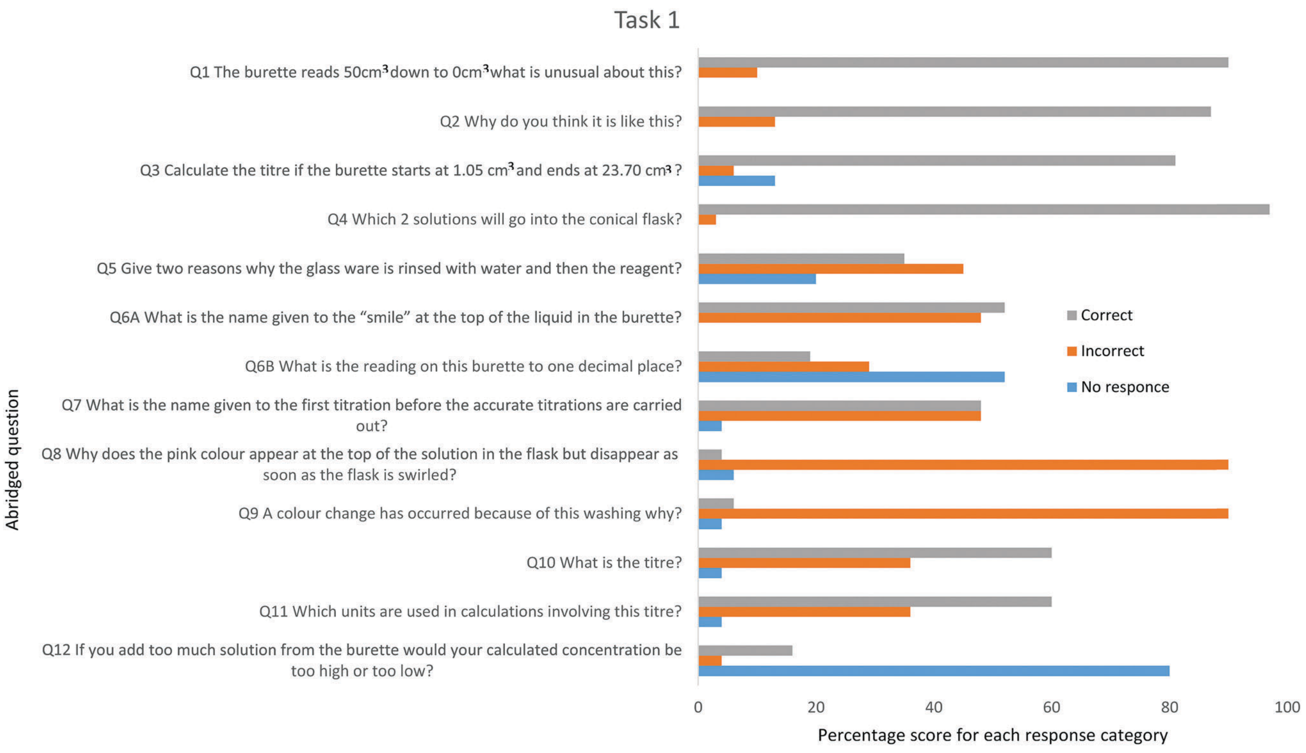

Fig. 7 Group T student responses to pre-laboratory questions. The responses show students are less successful in answering questions that require an understanding of the underpinning concepts compared to questions that require knowledge about procedures.

remained untrained in ''Exploratory Talk''. Future iterations will place more emphasis on oracy and how laboratory talk can be structured more effectively (Kind *et al.*, 2011).

Task 2 collecting data

Task 2 activity sheet is available in Appendix 3 (ESI†). The Task 2 data shows an increase in the number of questions that are left without a response. Additional work was found in class books rather than the Task 2 sheets indicating that results were being recorded and calculations completed. Appendix 4 (ESI†) summaries the students' responses to the Task 2 questions. The Peer Observation Checklist had actions ticked off but no responses. Future iterations must consider limiting the activities beyond data collection that are required during a practical episode whilst encouraging links between the practical procedures and the underlying concepts.

Digital badges

Anecdotal reports suggest that students were not motivated by the reward of a digital badge. The reasons for this are likely to be two-fold. Firstly, school students have very little, if any, experience of digital badges beyond those issued in games. Fourteen and fifteen-year olds are not yet thinking about application processes and curriculum vitae development, so the potential of digital badges has yet to appeal to them. Secondly, it has been reported that obtaining badges for taking part fails to provide the motivation that occurs when a badge must be authentically earned (Abramovich *et al.*, 2013). In this study the completion and submission of pre-laboratory Task 1, Data collection Task 2 and the Likert scale questionnaire were the parameters for receiving a badge, separating practical skill from assessment unlike the direct assessment achieved by submitting video evidence of practical skills. An image of the digital badge and criteria as issued to the students *via* email from the school VLE, has been reproduced in Appendix 5 (ESI†).

Limitations

The activities selected in this study had to fit within the confines of curriculum timetabling, and an exemplar video had to be available for the novel pedagogy. Neutralisation and crystallisation are both practical episodes specified by the exam board, they occur in sequential terms within the school calendar but are designed to develop different laboratory skills. In addition, the neutralisation procedure is a higher tier activity, meaning the content is more demanding and aims to distinguish between those students capable of achieving grades 5 up to 9. The sequential order of the episodes, dependent on school assessment timetable, resulted in Group T being retested on neutralisation (novel pedagogy) and crystallisation (traditional pedagogy) practical exam questions after different time intervals, the ten weeks were measured from the completion of the crystallisation task. This implies that improved retention of neutralisation (novel pedagogy), the first practical episode, was greater than reported here.

Each analysis conducted met the assumptions required to use inferential statistics. That control cohort C1 showed a statistically significant difference (Fig. 2 and 3) in attainment between the two procedure questions and that control cohort C2 showed a statistically significant difference in calculation question attainment (Fig. 3) as compared to cohorts C1 and T are suggestive of additional factors, affective, epistemic, or instructor interaction, influencing outcome. As a results comparison of attainment made within a cohort are perhaps more secure than those made between cohorts. To ensure marking bias was reduced, a rubric was employed in the first instance followed by moderation and agreement of marking samples. The marking sample revealed one group's work was not in agreement with the other two, although Cohen's Kappa suggested good agreement (Landis and Koch, 1977), where discrepancy was noted items were remarked and the agreed mark was submitted.

The use of student minimum target grades, based on primary school attainment, as a baseline is not secure however, as a population, variance between individuals with different primary school experiences should be accommodated for, ANOVA analysis of the groups' Minimum Attainment Targets (MAG) and Levene's test of homogeneity indicate that group variances are equal and ANCOVA analysis using MAG as a covariant was employed. At the time of writing GCSE grade boundaries remain unavailable hence, no inference between attainment scores and GCSE grades have been made. In addition to which extrapolations between six-mark questions scores and GCSE grades would not be secure.

Learning experiences should be designed to reduce working memory load to promote schema acquisition (Sweller, 1994) Task 2 and the peer-observation sheet were text dense and required completion during the practical work future iterations will need to aim address this. In algebra using worked examples has been shown to promote learning more effectively, measured by student performance in subsequent tests, than problem solving (Carroll, 1994), similarly the use of questions here may not be an effective tool for promoting learning.

Conclusions

This work set out to design and test a novel pedagogy for practical work in GCSE chemistry because of concerns raised by the introduction of terminal assessment of which fifteen percent of the marks will be dedicated to exam questions that specifically draw on the experience students have gained from doing practical work. Although no direct measure of cognitive load was made, the instructional design included modifications reported to limit cognitive load (de Jong, 2010; Kirschner, 2002).

The novel pedagogy used pre-laboratory preparation outside of lesson time to extend the learning opportunity and build familiarity with the procedure prior to implementation. Students reported affective benefits of this novel approach and this was supported by a statistically significant increase in retention. If students feel that they understand something or feel that a method of instruction is successful, it can indicate that learning has occurred, such confidence is not consistent with situational motivation. The affective benefits reported by the students suggests that in this instance the novel pedagogy is beneficial.

There was no statistically significant difference between the test cohort's initial attainment grades following each mode of instruction. When the students were retested, without warning, the novel pedagogy resulted in higher attainment grades than those obtained following the traditional pedagogy. That this novel pedagogy has resulted in a statistically significant increase in the retention of knowledge, suggests that pre- laboratory episodes for GCSE candidate may be beneficial. The author recognises that further work is required to draw conclusions beyond this study, further testing and a larger sample size are both required to do so.

Conflicts of interest

There are no conflicts to declare.

Acknowledgements

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Chapter 3: A holistic framework for developing purposeful practical work.

<table>
<tr><td>Paper 3</td><td colspan="3">Hennah, N., Newton, S., & Seery, M. K. (2022). A holistic framework for developing purposeful practical work. <i>Chemistry Education Research and Practice.</i> <i>23</i>(3), 582–598.</td></tr>
<tr><td>Author’s contribution</td><td colspan="3">The first author’s contribution
• The plan, design, and implementation of the project
• Collection and analysis of data
• Lead writer for the paper
• Executing the submission process
The second author’s contribution
• Made and produced “one video two voice over” videos.
The third author’s contribution
• Author two’s supervisor
Guiding and proofreading the manuscript</td></tr>
<tr><td colspan="2">Other impacts</td><td>Citations (Google scholar)</td><td>Altmetric</td></tr>
<tr><td colspan="2">Featured in RSC <i>Education</i> in Chemistry magazine.
Speaker at:
Methods in Chemistry Research 2018 (invited)
University of Southampton Post-16 Chemistry Teachers' Conference 2018 (invited)
2018 The Open University School of Life, Health, and Chemical Sciences Educational research group (invited)
2019 ASE annual conference
Speak for Change Parliamentary inquiry evidence 2020 (invited)
Poster presented at:
Methods in Chemistry Research 2018
CLEAR Lab Symposium 2020
RSC online poster competition 2018 and 2019</td><td>4</td><td>22</td></tr>
</table>

What circumstances led to Paper 3?

Practical work in schools is deemed an important component of science education as it introduces learners to the phenomena, methods, and tools of science (Ofsted 2021). Practical activities in schools are contrived learning experiences (Hofstein & Lunetta 1980) but their efficacy for developing conceptual understanding has been contested for decades (see for example, Abrahams & Millar 2008; Abrahams & Reiss 2012).

Despite this, “supporting and consolidating scientific concepts” is one of three reasons for carrying out practical work stated in the GCSE exam specification (AQA 2019, p. 101). To develop investigative skills, and to build and master practical skills are the other reasons provided. The curriculum reforms discussed for A level in Chapter 1, also replaced all direct assessment of GCSE chemistry practical work with “practical-themed examination questions” (Moore *et al*., 2020, p. 7).

The students’ ability to manipulate equipment cannot be assessed in written exams, so it is the students’ knowledge of experimental procedures and techniques, data presentation, data analysis, and the interpretation of data with respect to scientific concepts that is assessed. The work discussed in Chapter 2 demonstrated that the students’ ability to retain information was seen to improve. However, the intervention was not seen to have a significant impact on the students’ ability to build the knowledge and understanding needed for improved attainment in the indirect assessment.

Johnstone and Wham (1982) reasoned that learning was impaired because the number of new or unfamiliar entities presented during laboratory episodes overload working memory space. The term cognitive load refers to the demand placed on working memory by a range of cognitive processes such as comprehension, problem solving, schema automation, and schema construction. Although Johnstone and Wham were working in the field of undergraduate chemistry, I assume that the principle is the same in the school context.

According to cognitive load theory (CLT), when the limited capacity of working memory is overloaded by the competing demands of these processes, learning is impaired (de Jong 2010). From Johnstone and Al-Shuaili (2001), I understood the importance of pre-laboratory preparation to learning. Thus, the instructional approaches discussed in Paper 1, Chapter 1 and Paper 2, Chapter 2 both employed video as a method of pre-laboratory preparation. However, the results discussed in Paper 2, Chapter 2 indicated that the affective impact of the intervention had been more positive than the effect on learning. The affective benefits of using video to learn psychomotor skills has also been reported in the field of dentistry education (Botelho *et al*., 2019).

The multicomponent model of human cognitive architecture describes working memory as having two processing systems that initially process visual and verbal information independently (Baddeley 2010). According to the modality effect, information presented in more than one modality is divided across these systems and effectively reduces the cognitive load applied (Kirschner 2002). The use of video to support learning is also justified by dual–coding theory (Clark & Paivio 1991) which proposes that higher levels of learning retention, recall and transfer of learning to other environments occurs with multimedia presentations. This is because videos are thought to allow learners to produce both verbal and visual mental representations of the content, these are held in the visual and auditory working memory where the information is organised and integrated with prior knowledge (Mayer 2005). Thus, an instructional video specific to a practical task could reduce the cognitive load imposed by this method of instruction more than a written method of the same procedure.

The laboratory can be understood to be a complex learning environment where knowledge, skills, and attitudes are developed simultaneously to acquire complex skills and competencies (Seery *et al.,* 2019). It is important to consider what information is contained in instructional material and how it is presented, as this must first be processed by the working memory (de Jong 2010). The four-component instructional design model (4C/ID) is an instructional design approach specific to complex learning environments (van Merriënboer 2019).

The 4C/ID identifies two categories of information that should be presented to students separately. These are *supportive information*, which is the conceptual underpinnings, and the *just-in-time,* procedural information, required to carry out the task. I hypothesised that separating out procedural and conceptual information in the pre-laboratory preparation video could provide further support for students by focusing their attention on the just-in-time procedural information needed for the task. Then, having completed the practical lesson, the underlying concepts connected to procedure could be contextualised by reflecting on what had been done.

Attention and memory are inextricably linked, attention determines what is encoded by the space-limited working memory, and the memory of experience guides attention (Chun & Turk-Browne 2007). Separating the information out, guides the learner explicitly to what needs to be attended to.

From this understanding, I conceived the one video two voice overs[4] instructional approach. The practical task described by the exam board as meeting the assessment criteria was filmed. The first voice over details a step-by-step explanation of the equipment and procedure including the results, and then a second voice over is applied to the same footage that details the chemistry concepts that underpin the task and interpretation of the results.

Paper 3 was designed to address the following research questions:

1. Are there significant differences in summative test attainment scores between students exposed to Lab Talk and Lab Roles and their counterparts not exposed to this approach?

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[4] https://www.youtube.com/@chemistryonevideotwovoiceo3547 The One Video Two Voice Over project is a collaboration between Naomi Hennah of Northampton School for Videos made by Sophie Newton and Angus Preston final year undergraduate chemistry education project students, The University of Edinburgh.

2. What influence does the inclusion of one video two voice overs have on students' perception of their learning experiences?

The videos described in Paper 3 were made by Sophie Newton as her final year undergraduate education project at the University of Edinburgh for which I was her co- supervisor.

So, what interventions were implemented in Paper 3 and how was their impact gauged?

Designing an assessment instrument

Many teachers have expressed concerns about the amount of curriculum content that needs to be covered in the GCSE exams compared to the time available for teaching.[5] One of the major drivers for the research described in this thesis was to make the most out of practical episodes by using video to extend the activity beyond the classroom.

As described in Paper 3, the school has three equivalent chemistry groups which afforded the opportunity to adopt a quasi-experimental approach. In addition to seeking all the appropriate ethical permissions from the school, teachers, and students, it was important to minimise the disruption to the normal teaching and learning schedule.

Investigating the efficacy of the one video two voice over instructional approach required an assessment instrument comparable in level to the GCSE examinations but specific to the topic of study. Initially I produced a multiple-choice quiz (MCQ) however, assessment literature presented several criticisms about this approach such as, testing knowledge rather than understanding or rewarding surface rather than deep learning (Johnstone & Ambusaidi 2000). This concern can be overcome by including two-tier multiple-choice questions where tier 1 is a fact-based MCQ question requiring information recall, and tier 2 is an open response reasoning-based item (Gero *et al.*, 2019).

Figure 3.1 provides examples of the two styles of questions used to assess students' knowledge and understanding of the concepts that underpin the Making Salts practical task. The students, unfamiliar with this assessment approach, selected more than one MCQ answer per question, and many of the open response items were left blank. No marks were awarded if more than one response was selected. Although this approach was time efficient in terms of marking, it did not

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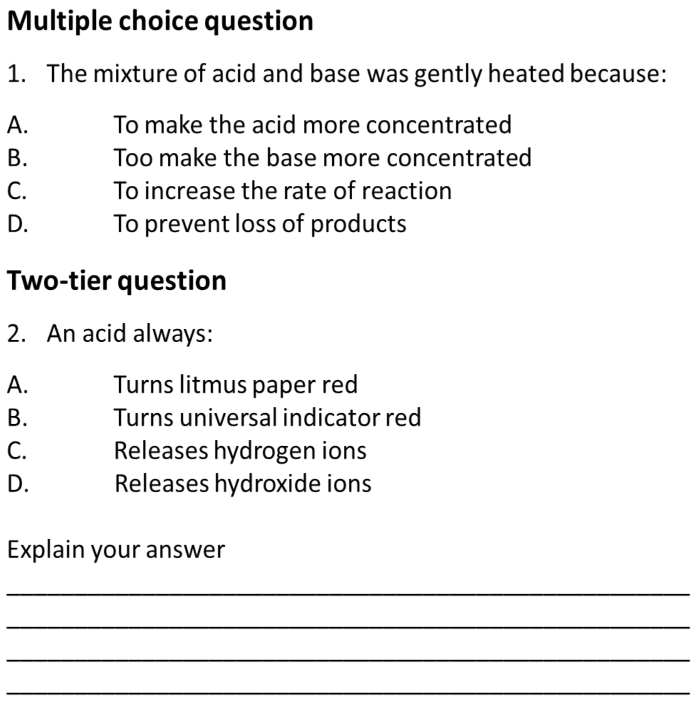
[5] See for example the RSC The Science Teaching Survey 2022 available from https://www.rsc.org/policy-evidence-campaigns/chemistry-education/education-reports-surveys-campaigns/the-science-teaching-survey/2022/too-much-content-not-enough-time/

provide the students with the opportunity to demonstrate their knowledge and understanding of the practical task.



Multiple choice question

1. The mixture of acid and base was gently heated because:

A. To make the acid more concentrated
B. Too make the base more concentrated
C. To increase the rate of reaction
D. To prevent loss of products

Two-tier question

2. An acid always:

A. Turns litmus paper red
B. Turns universal indicator red
C. Releases hydrogen ions
D. Releases hydroxide ions

Explain your answer
____
____
____
____

Figure 3.1, a sample MCQ and two-tier question from the first iteration of the Making Salts one video two voice over trial.

In trialling the assessment instruments, it was ethically important to make sure that the responses were anonymous. I had wanted to be able to track individuals progress between rounds of the quizzes. The students were asked to select false names, unfortunately many then forgot their chosen name between rounds. Instead, I asked the students just to provide their minimum attainment grade (MAG).[6] The purpose of tracking students was to try to ensure the data collection was as consistent as possible, avoiding for example a situation were just the highest achieving students were sampled one round and the lowest the next. For each round of the test and each class, I was able to calculate the mean MAG value to ensure that there was no statistically significant difference within a class.

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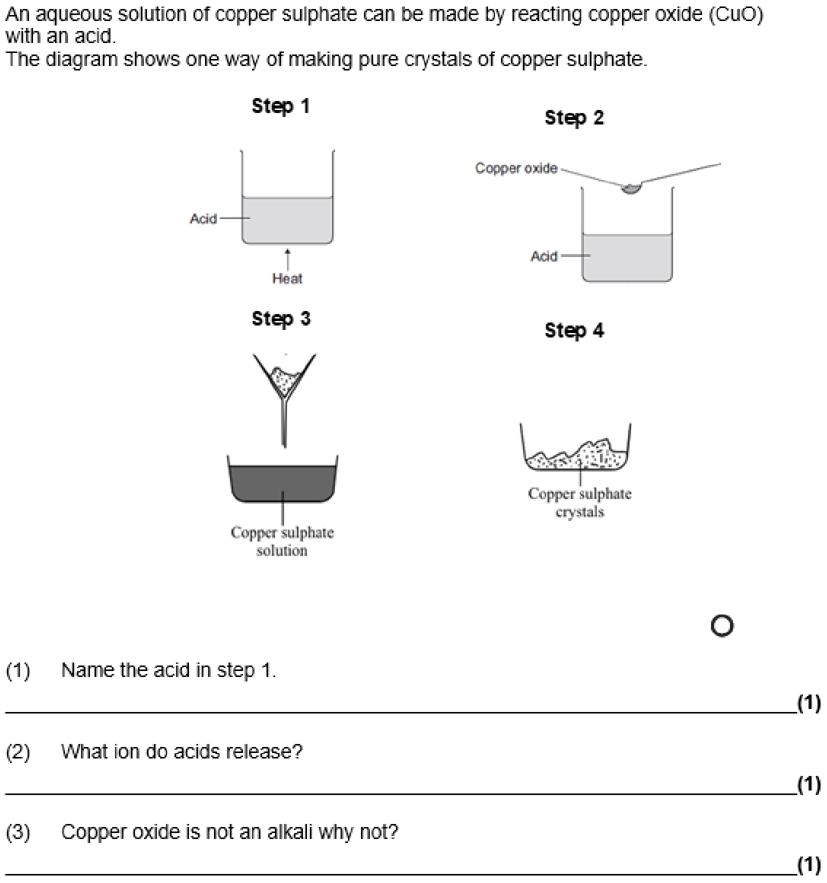
[6] The minimum attainment grade (MAG) is a component of school performance measures. A student's MAG is their forecast GCSE grade based upon their Key Stage 2 (KS2) results from primary school (Hennah 2019).

The assessment instrument designed for the final iteration was made of AQA produced practical-themed examination questions as shown in Figure 3.2. Exposure to exam style questions is important as students must understand the disciplinary knowledge and literacy practices that are the criteria by which their work is judged (Freebody *et al.*, 2008). Conversely, the marking load of open response exam questions is far greater and more subjective than MCQ quizzes.



An aqueous solution of copper sulphate can be made by reacting copper oxide (CuO) with an acid.
The diagram shows one way of making pure crystals of copper sulphate.

(1) Name the acid in step 1.

____ **(1)**

(2) What ion do acids release?

____ **(1)**

(3) Copper oxide is not an alkali why not?

____ **(1)**

Figure 3.2, an example of the practical exam style questions produced by the exam board AQA.

Using one video two voice over resources

To use videos as an effective educational tool requires teachers to consider: how to manage cognitive load of the video; how to maximise student engagement with the video; and how to promote active learning from the video (Brame 2016). The videos design was informed by cognitive load theory so the second and third considerations are discussed below.

The talk group in Paper 3 were organised into a group of 3 for all their practical work. So, to maximise student engagement with the video, the students were told that each group would have to complete a storyboard to construct the procedure, and have it checked before they could begin the practical task. This approach provides incentive to watch and engage with the video by increasing the task value. Task value results from a decision-making process in which the student takes into consideration the importance of doing well on a specific task, the personal interest of the content of the task, and its usefulness in relation to future personal goals, as well as the perceived negative aspects of engaging in the task (Metallidou & Vlachou 2007).

The storyboard activity also facilitated the creation of an active learning environment. Lab talk protocols were introduced to help the students collaborate and participate in meeting the shared goal of completing the storyboard. If a group member had not watched the video, they would not be able to contribute to the discussion. When learners are not able to participate in an activity and /or they sense of that others might perceive them negatively, a less competent identity can develop (Morita 2004). Thus, watching the video is beneficial to both the group and self.

Group work

As the research progressed my knowledge and understanding of factors that influence practical work continued to grow, and that net I had used to deconstruct practical work in Figure 2.3 appeared overly simplistic. For example, cognitive load and social constructivism were not conceived as interacting. Whereas, when members of a group coordinate and communicate the intrinsic cognitive load of the task will be distributed among the group which lowers the load experienced by an individual's working memory (Kirschner *et al.,* 2009).

I theorised that if we could facilitate collaboration, learning would be enhanced but I needed a model to understand group interaction. A practical guide to teamwork from the field of human resources (Salas *et al.,* 2015), describes a heuristic of 9 critical considerations that impact a team's effectiveness. In turn these considerations are subdivided into the team and around the team. The primary cognitions attitudes, and behaviours, that take place within the team are cooperation, coaching,[7] coordination, communication, cognition, and conflict.[8] Then external to but encapsulating the team, are influencing conditions; culture, composition, and context, which determine how well teams engage in teamwork.

Recognising the importance of teamwork, specific roles were introduced so that the students' talk and actions were scaffolded Indeed, the students working in the scaffolded cooperative learning environment perceived their confidence in relation to practical-related tasks at higher levels than those in other groups. Furthermore, the combined effect of all these interventions was that the students achieved significantly higher attainment scores in GCSE chemistry examination practical-themed questions than those students who prepared for the practical task by watching either the novel videos or standard instructional videos during the lesson.

Cultural-historical activity theory

The critical considerations impacting teamwork will also impact the broader practical lesson. However, most of the research reviewed by Hofstein and Lunetta (1980) had reportedly failed to consider cultural and contextual components including the learning environment or teacher behaviours such as instruction style, and how the curriculum is operationalised. Understanding the variety of components responsible for the actuality of a practical task affords the opportunity to understand the practical task's effectiveness in terms of what students do and what students learn (Abrahams & Millar 2008).

Cultural-historical activity theory (CHAT) is a framework for understanding complex learning environments that takes a socio-material perspective and considers learning and practice inseparable (Yamagata-Lynch, 2010). The theoretical CHAT framework, illustrated in Figure 3.3, considers human cognition and its development as products of social interaction in which artefacts of all kinds may be employed to learn and communicate (Roth & Lee 2007). There are seven separate but interconnected elements in the GCSE chemistry practical task activity system. The subjects are the students who work in small groups carrying out the practical task with the object being purposeful practical work. The object can be thought of as an objective, that is why the

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[7] Coaching in the context of the school laboratory, is understood to be comparable to Vygotsky's notion of a more knowledgeable other (MKO) (Vygotsky & Cole 1978) except that the peers are equal, so the direction of learning is situational. The position of MKO will be occupied by different participants depending on the task demands in a manner akin to synergy, the reciprocity of learning between siblings (Gregory 2001).

[8] The term conflict refers to task conflict or challenge for which multiple solutions may be presented by the team and they must select the most viable to proceed.

subjects are carrying out the practical activity and the outcome is the quality of student responses to practical themed exam questions as measured using the exam board mark scheme.

The tools or mediating artefacts include technical tools such as laboratory equipment; psychological tools which include written instructions, verbal instructions, the visual images in practical videos; and other people such as the teacher and fellow learners can provide help and support.
The rules refer to the explicit and implicit conventions and regulations that regulate the actions and interactions within the activity system (Engeström *et al*., 2002) specifically laboratory conventions and teacher expectations. The community refers to individuals/groups who broadly share the same object and consider themselves distinct from other communities, which is a particular class of learners and their teacher within a particular school. The community is subject to the ideological values advocated by the DfE, and privileged in England's education system which are, arguably, a reflection of the Organisation for Economic Co-operation and Development (OECD) current globalised ideologies (2019). Finally, the division of labour includes both the division of tasks between the members of the community and the vertical apex which embodies the division of power and status (Gifford & Finkelstein 2020).
Understanding purposeful practical work as an activity accepts that the three domains of learning are equally important as a deficit in anyone would impact the activity, and it is the activity of carrying out the practical task that builds the knowledge and understanding that are assessed.

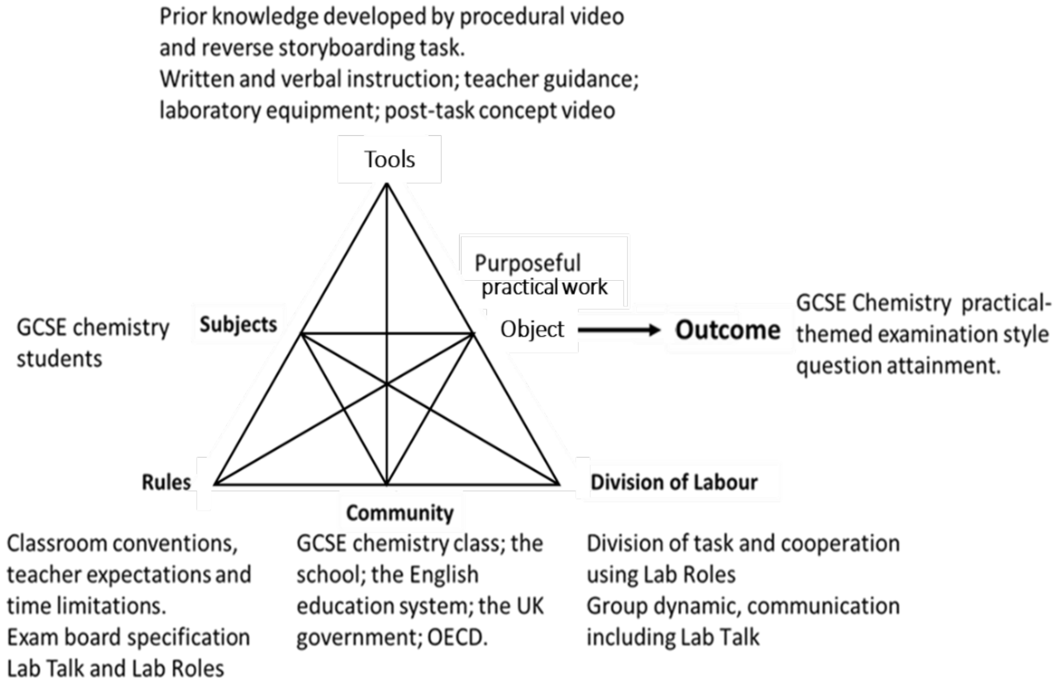


Figure 3.3, the network of interacting factors that influence an activity as described by cultural-historical activity theory (CHAT) (Engeström 2008) applied to a GCSE chemistry practical task.

What now for my professional practice?

The work that surrounded Paper 3 transformed the purpose of practical work into a site of activity. For the students to build the knowledge and understanding needed for indirect assessment, the practical activity requires that learners work and communicate in cooperative groups. The CHAT framework supports a deeper understanding of how factors such as, an individual's or the group's identity, engagement, and participation are interconnected. Thus, determinants such as social hierarchies, science capital, and the sense of how one is perceived by others, all impact on the activity and shape the outcome.

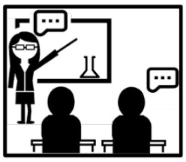
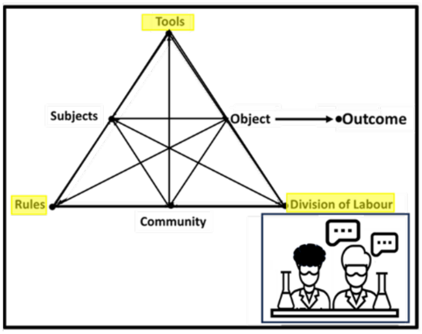
Before the lesson	**During the lesson**	**After the lesson**
Exemplar procedural video	 Discussion and teacher demonstration  Hands-on task arranged to disrupt the established norms  Follow up discussion and questions	Exemplar concept video

Figure 3.4 illustrates the emphasis placed on developing teamwork to support learning through GCSE practical activity, informed by the CHAT framework, as described in Paper 3. The modifications to my practice are coloured yellow and includes the one video two voice over resources, which provides pre-laboratory preparation and a follow up consolidation of underlying concepts.

I sought to disrupt the established norms to develop a more cooperative and equitable learning environment by introducing Lab Roles. The three roles; manager, technician, and materials handler, described in Paper 3 were very well received. The novelty of being a manager able to direct their partners was particularly valued by the students. The desire to have this position of responsibility helped to ensure that the roles were rotated within the trios between practical activities. Further investigation into roles is required. During measuring activities such as titration and rates of reaction, each role participated equally, whereas during observation activities such as electrolysis, the manager had less to do. It is when students are not fully occupied that less productive behaviours began to re-emerge.

The modifications to the organisation and delivery discussed in Paper 3 are summarised in Figure 3.4. I continue to explore how to organise practical work in my lessons to facilitate a cooperative environment. I have started to call the roles A, B, C, and I break the practical task up into small units for each role. For example, person A may be directed to collect the goggles and lit splint for their group; person B sets up the Bunsen burner, tripod, and gauze; and person C collects and measures out the acid. This very structured teacher-led approach works well for setting up and clearing away, but some disengagement during the task will arise if there is not enough hands-on activity for everyone to share. The converse is true when the students are arranged in pairs. It takes longer to set up, time becomes a constraint and clearing up is left incomplete.

A more structured approach to teacher-led discussion has also been adopted so that students are asked a question and answer is provided and then the class is asked if anyone would like to build on or challenge that answer. In doing so, we are modelling how to listen, and use talk to think together.

Other professional impacts

I can report that of the 29 students who formed the group named “Talk” in Paper 3, ten studied A level chemistry and went on to higher education to study a range of courses that included medicine, dentistry, and chemical engineering.

The opportunity to co-supervise a second final year undergraduate resulted in the production of a one video two voice over film for the chromatography required practical.[3]. This video, made by Angus Preston, was designed to consider paper chromatography from the three apices of Johnstone's triangle (Johnstone 1982). Unfortunately, the disruption brought about by the pandemic prevented further exploration of this resource, but I do use it for pre-laboratory preparation.

Other professional impacts	**Audience**
2018 CERG Fellowship Using oracy to reduce cognitive load in the laboratory presentation and poster 2019 ASE annual conference.	International event for science educators
Oracy All-Party Parliamentary Group written evidence and presentation	Members of parliament and Voice 21
Hennah, N. 8 ways to inspire students about the environment *Education in Chemistry* [online] 19 March 2019. Available at https://edu.rsc.org/ideas/8-ways-to-inspire-students-about-the-environment/3010250.article	Education in Chemistry magazine readers
Hennah, N. How thinking about thinking improves problem solving *Education in Chemistry* [online] 3 April 2019. Available at https://edu.rsc.org/feature/thinking-about-thinking-promotes-problem-solving/3010273.article	Education in Chemistry magazine readers
Hennah, N. Stoking debate in the classroom *Education in Chemistry* [online] 26 April 2019. Available at https://edu.rsc.org/ideas/debate-in-the-chemistry-class/3010407.article	Education in Chemistry magazine readers
Hennah, N. Choosing the right practical simulation *Education in Chemistry* [online] 26 May 2021. Available at https://edu.rsc.org/ideas/how-to-choose-the-right-practical-simulation/4013717.article	Education in Chemistry magazine readers
Hennah, N. Soil, species and sustainable schools *Education in Chemistry* [online] 22 September 2021. Available at https://edu.rsc.org/ideas/sustainable-use-of-terrestrial-ecosystems/4014413.article	Education in Chemistry magazine readers

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A holistic framework for developing purposeful practical work

Naomi Hennah, *[a] Sophie Newton[b] and Michael K. Seery[c]

This work applies a cultural historical activity theory (CHAT) framework to understand how the outcome of a high school laboratory task may be positively influenced without making changes to the hands-on practical task itself. Informed by cognitivism, novel practical instruction videos that were based on the same video but had different audio content ("one video two voice overs") have been developed to provide opportunities to prepare for the practical task procedure and then to reflect upon the task's underlying concepts. We use the CHAT framework as a guide to change pupils' lab roles and rules of engagement were made to structure student interaction and facilitate an equitable and cooperative learning environment. We demonstrate that students benefit from these interventions and achieve significantly higher attainment scores in GCSE chemistry examination practical-themed questions than those students who prepared for the practical task by watching either the novel videos or standard instructional videos during the lesson. In, addition the students working in the scaffolded cooperative learning environment also perceived their confidence in relation to practical-related tasks at higher levels than those in other groups. This work contributes a novel approach to laboratory teaching by placing greater emphasis on dialogic processes as a tool accomplish a practical-based activity.

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Introduction

Assessment of practical work

In England, the study of science is compulsory up to age 16, culminating in the General Certificate of Secondary Education (GCSE) examination, with the study of chemistry accounting for approximately one third of the science curriculum. The national curriculum sets out the programme of study and attainment targets for GCSE chemistry. Exam boards such as the Assessment and Qualification Alliance (AQA) build a specification identifying key skills, understanding, and knowledge that students are expected to have gained by the end of their course. The specification aims to balance "what works in the classroom and what can be accurately marked and graded" (AQA, 2014). The exams regulator, Office of Qualifications and Examinations Regulation (Ofqual), ensures that the specifications are fair and meet the national curriculum criteria.

The examination boards specify the apparatus and the techniques which 15 to 16 year-old learners' must gain experience of, by completing a minimum number of 8 practical tasks. Students are not assessed carrying out these activities, but they need to keep contemporaneous records, and schools must confirm to exam boards that they have enabled their students to do the full range of practical work. Fifteen percent of the GCSE chemistry examination marks are assigned to practical-themed questions that draw on students' experience of doing practical work, their investigative skills, and their ability to apply this knowledge in novel contexts (Ofqual, 2015). Teachers can choose whether practical episodes are conducted by the students, or are teacher demonstrated, and may also choose to employ other teaching aids such as videos or simulations (Moore *et al.*, 2020).

Schools in England are encouraged to include purposeful practical activities as part of the day-to-day teaching of learning. As "[a]ssessment operationalises outcomes and hence defines them" (Millar, 2013, p. 55), there are mounting concerns, exacerbated by the Covid-19 pandemic, that learners will be provided with fewer opportunities to conduct practical work themselves (Cutler, 2020).

Purposeful practical work

Practical work in this context refers to the collection of data through investigation, measurement, and observation of phenomena intending to develop students' understanding of scientific methods and their ability to safely use apparatus and follow practical procedures (Abrahams and Millar, 2008). Purposeful practical activities are defined as those in which the

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teacher knows the purpose of the activity, which "should be planned and executed so it is effective and integrated with other science learning'' (Gatsby, 2017, p. 45). Purposeful practical work requires that students consider "the thinking behind the doing'' (Oshima and Roberts, 2018, p. 69) in addition to developing practical and investigative skills. The AQA examination specification states that by "focusing on the reasons for carrying out a particular practical, teachers will help their students understand the subject better, to develop the skills of a scientist and to master the manipulative skills required for further study or jobs in STEM subjects'' (AQA, 2019a, p. 101). According to the specification, the reasons stated for doing practical work in schools are: to support and consolidate scientific concepts, to develop investigative skills, and to build and master practical skills.

Thus purposeful school practical tasks are those that facilitate the acquisition of complex cognitive skills; the integration and transference of attitudes, knowledge, and skills. Kirschner and Van Merriënboer (2008) use the term "complex learning'' to describe such acquisition of complex cognitive skills. However, research has indicated that school practical work is rarely purposeful (see Cukurova *et al.* (2017) for a comprehensive review). Johnstone (2006, p. 58) suggests that the problems with practical work arise because of they become overwhelmed with "written and verbal instructions, unfamiliar equipment and chemicals, observing and recording'', leaving little capacity for cognitive processing. This context means that students try to manage the load by using "written instructions as a 'mind-in-neutral' recipe''.

This work explores how practical activity designed to meet the AQA GCSE chemistry specification requirements may be adapted so that students are better able to answer practical-themed examination questions. To do so we will begin by considering factors known to impact upon students' thinking and learning during complex tasks. Then we will consider a theoretical framework for exploring the impact of adaptions informed by these factors on students' performance on practical-themed examination questions. As previously discussed there is an apparent dichotomy between the requirements of practical assessment on the one hand, and the demands of "purposeful practical work'' on the other. For this reason, the analytical framework must consider not just the separate components of the practical activity but the systemic whole recognising the existence of such contradictions. We will then demonstrate the framework and adaptations in action before discussing the implications this work has for practical activity.

Theoretical frameworks

Cognitivism

Cognitive load is the term used to describe the demand placed on the working memory by a task, and cognitive load theory (CLT) applies what is known about human cognitive architecture to the study of learning and instruction. Briefly, when load becomes too high, learning is impaired (Van Merriënboer, 1997; Chen *et al.*, 2018; van Merriënboer and Kirschner, 2018). The importance of conducting hands-on practical tasks is supported by embodied cognition. Embodied cognition asserts that cognitive processes, including information processing and learning, are inextricably linked with all forms of sensory input (not just sight and sound) including physical and environmental experiences of an individual (Barsalou, 1999). Thus a learner's motor functions, including gestures and tactile experiences, play a similar role to, and introduce similar effects as, visual and auditory information in learning. The importance of learners carrying out hands-on practical tasks is further supported by the distributed attention model of working memory (Sepp *et al.*, 2019), specifically, that physical movement can expand working memory capacity (Bokosmaty *et al.*, 2017).

Research in CLT has already identified several empirically supported effects that can inform teaching practice and the design of learning materials. For example, the 'modality effect' – using both auditory and visual channels – increases the capacity of working memory, and facilitates more effective learning (Mousavi *et al.*, 1995; Jeung *et al.*, 1997; Tindall-Ford *et al.*, 1997). The modality effect occurs in mixed-mode instruction when visual learning materials (such as diagrams) are supplemented with complementary auditory information, such as a verbal explanation in place of written text. Drawing upon instructional design for complex learning (van Merrienboer *et al.*, 2003), Seery *et al.* (2019) recommend that the two categories of knowledge that are required to understand and conduct a laboratory task are identified separately in curriculum design. The first is "supportive information'' – conceptual knowledge needed for the students to understand the task and the rationale of carrying it out, or what has been called the "the thinking behind the doing'' (Oshima and Roberts, 2018, p. 69). The second is "procedural information'' – procedural knowledge that enables students to successfully carry out the task. There is a clear shared purpose between the focus of Seery *et al.* on the undergraduate chemistry laboratory and Ofqual's GCSE chemistry practical work discussed above. As such, these laboratory curriculum guidelines can be used to inform school practice. Indeed following the call from Agustian and Seery (2017) for renewed emphasis for inclusion of pre-laboratory activities within the overall framework of laboratory learning in undergraduate curricula, the benefits of pre-laboratory preparation in a secondary school context have already been reported (Hennah and Seery, 2017; Hennah, 2019).

Collaborative learning

In schools, students habitually work in small groups of 2 to 4 learners when carrying out practical tasks, because of the need to share equipment (Christensen and McRobbie, 1994). However, group work can be viewed as advantageous. For example, Dillenbourg (1999) noted that social interaction between peers is fundamental to achieving learning. Moreover, Johnson and Johnson (1989) found classroom learning improves significantly when students participate socially, interacting in face-to-face collaborative learning activities with small groups of members. Jurkowski and Hänze (2015) report meta-analyses of educational studies that demonstrate positive effects of cooperative learning when compared to competitive or individual learning beyond knowledge acquisition which include social and motivational outcomes such as academic self-concept, social skills, and peer relationships.

Collaborative learning (Johnson and Johnson, 1989; Johnson *et al.*, 1991, 1998) can be defined as a learning situation during which students actively contribute to the attainment of a mutual learning goal and try to share the effort to reach this goal (Teasley and Roschelle, 1993). Collaborative learning should result in every group member learning something from the combined effort. When working together, students not only interact, they 'interthink' (Littleton and Mercer, 2013). The use of language and other modes of representation enables learners to link their individual minds to create a more powerful information-processing system which Mercer (2013) describes as the "social brain". Hands-on practical tasks afford students the opportunity to interact with each other as well as the procedures and materials of science. For example, a study of collaborative learning in a school laboratory reported an improvement in skill acquisition, conceptual understanding, and positive affective outcomes among the 12 year-old female participants (Raviv *et al.*, 2019).

There is an argument, based on CLT, which suggests that collaborative group work during complex learning tasks could help to overcome individual working memory limitations (Kirschner *et al.*, 2009; Kirschner *et al.*, 2011). Indeed, Kirschner *et al.* (2008) have shown that learning by an individual becomes less effective and efficient than learning by a group of individuals as task complexity increases. Furthermore, according to CLT, learners in collaborative groups are considered as a single information-processing system as the processing is divided across the group (Tindale and Kameda, 2000), in what Kirschner *et al.* (2011) call "the distribution advantage". Information must be recombined following division, and processing must be coordinated, but these costs are minimal compared to the gains from this division of labour when the cognitive load is high (Kirschner *et al.*, 2009).

The question arises of how group work can be transformed into collaborative learning. Leikin and Zaslavsky (1999) advise that learning materials need to be modified so that every member of the group is responsible for contributing to the group work and the group's success. Fransen *et al.* (2011) – in the context of computer-supported collaborative learning – report that assigning roles within a collaborating team has positive effects on the team's effectiveness. Frith and Singer (2008) noted that "when joint action requires cooperation, shared representations of task requirements and goals are very important to achieve better performance. Such sharing is referred to as common knowledge" (p. 3876). Edwards and Mercer (2013) describe the creation of "common knowledge" as an interactive, complex, and discursive process.

Drawing upon the literature cited above the importance of minimising learners' cognitive load during hands-on practical tasks is made clear and that failing to do so impairs learning. Furthermore, understanding that practical tasks are complex learning environments emphasizes instructional design and collaborative group work in which common knowledge is created, are means of lessening the cognitive load imposed by the task.

Sociocultural theory

In recognition of the potential benefits of student collaboration during practical work, we adopt a sociocultural approach (Vygotsky, 1978) which understands that knowledge is not transmitted from one individual to another but co-constructed through social interaction. Vygotsky (1978, p. 57) states: "every function in the child's cultural development appears twice: first, on the social level, and later, on the individual level; first, between people (interpsychological) and then inside the child (intrapsychological). This applies equally to voluntary attention, to logical memory, and to the formation of concepts. All the higher functions originate as actual relationships between individuals".

To explore the process through which individuals' learning is linked to their sociocultural context, Vygotsky conceived the Zone of Proximal Development (ZPD), which refers to the difference between what an individual can accomplish entirely on their own, and what they can do with the assistance of a more capable other (Cazden, 1981). The more capable other may be a teacher, tutor (human or electronic), or may arise through the structure of the activity (Smith *et al.*, 1991).

The application of sociocultural theory to chemistry education is well documented (see Finkenstaedt-Quinn *et al.*, 2017; Flener-Lovitt *et al.*, 2020; Moon *et al.*, 2017; Pazicni and Flynn, 2019 as recent examples). Collaborative learning may be rationalised by Vygotsky's (1978) concept of the ZPD because, a more capable learner can provide "scaffolding" (Wood *et al.*, 1976, p. 90) for a less capable learner to accomplish a task that they could not accomplish alone. Adopting a sociocultural approach to learning understands education to be a dialogic process shaped by cultural and historical factors, and thinking, learning, and development cannot be understood without taking account of the intrinsically social and communicative nature of human life (Mercer, 2007).

Vygotsky's notion of mediation suggests that the individual does not establish a direct relationship with the world, but that this relationship is mediated through the use of tools (Lantolf and Beckett, 2009). Sociocultural theory describes human mental functioning as a mediated process that is organised by activities, concepts, and cultural artefacts (Ratner, 2002). An example is chemical concepts; which are not tangible (Lemke, 1990), but constructed through mediational means such as language, symbols, and reproducing chemical phenomena. Indeed sociocultural theory provides further support for hands-on practical tasks as it is through social negotiation and participation in cultural activities that understanding is generated (Packer and Goicoechea, 2000).

Vygotsky viewed language as the primary mediational tool because it has both an intrapersonal and an interpersonal function that mediates learning and development (Lantolf *et al.*, 2015). Artefacts help individuals internalise social practices that are then externalised as cultural actions or behaviours. Watching a pre-laboratory video can be understood to be such an artefact, supporting support learners in carrying out a practical task. As such, adopting a sociocultural approach places emphasis on the quality of dialogue and collaborative social interactions arising out of these externalised practices.

Cultural historical activity theory (CHAT)

Cultural Historical Activity Theory (CHAT) is a theoretical framework that considers human cognition and development as products of social interaction in which artefacts of all kinds may be employed to learn and communicate (Vygotsky, 1978; Engeström, 2008). CHAT affords the opportunity to consider strategies to reduce the cognitive load of a task and improve learners' collaboration and communication within the rigid confines of the National Curriculum.

CHAT has been widely utilised in education (for a comprehensive review see Nussbaumer, 2012; Plakitsi, 2013) and may be employed as a practical intervention methodology to improve learning because it provides a conceptual framework for understanding the inter-relationships between activities, actions, operations and artefacts, the subjects' motives and goals, and aspects of the social, organisational, and societal contexts within which these activities are framed (Engeström, 2008).

CHAT is composed of seven components; subjects, objects, community, mediating artefacts/tools, rules, division of labour, and outcomes (Engeström, 1999). In CHAT, the relationship between subject and object is pictured as a triangle, known as the activity system (Fig. 1). The activity system constitutes the minimal unit of analysis, a map of complex instructional activity within a single, integrated system (Roth *et al.*, 2009).

Within the activity system, the subject may be an individual or group of individuals participating in a specified activity and the object is the motivating influence behind the subject's participation in this activity. As shown in Fig. 1 the subject acts upon the object, with actions is mediated by tools to produce the activity outcome. Wertsch suggests that artefacts or mediational tools cannot be separated from the process of achieving a goal and the mediation of knowledge and skills is dependent upon the tools used in the process of meaning-making (Wertsch and Rupert, 1993; Wertsch, 1994). The subject acts within a community in the context of rules that the entire community follows. Finally, division of labour describes how the tasks and responsibilities are shared among the participants engaged in the activity (Cole and Engeström, 1993).

It is important to appreciate that every aspect of the system affects and is affected by the other aspects constituting the activity that produces the outcome. The system is constantly working through contradictions within and between its elements meaning that, for example, rules, community, and the division of labour are all mediators and dialectically linked (Lee, 2011).

CHAT has been used in science education studies to consider processes as disparate as representations of science in textbooks (van Eijck and Roth, 2008), novice teachers' transitions into teaching (Saka *et al.*, 2009), one student's engagement in science classroom laboratory work (Andrée, 2012), pedagogic practices in informal science education contexts (DeWitt and Osborne, 2007), culture and language-influenced curriculum materials in physics (Morales, 2017), and recently, university chemistry education (Keen and Sevian, 2022).

The GCSE chemistry practical activity system

The seven CHAT elements in the English GCSE chemistry practical activity system are illustrated in Fig. 1. The subjects are the students who work in small groups to carry out the practical task, and the object is purposeful practical work. The object can be thought of as an objective, leading to the outcome being the quality of student responses to practical-themed exam questions, as measured using the exam board mark scheme (AQA, 2021).

The tools or mediating artefacts include technical tools such as laboratory equipment that help the subject effect things; psychological tools such as written instructions in lab books,

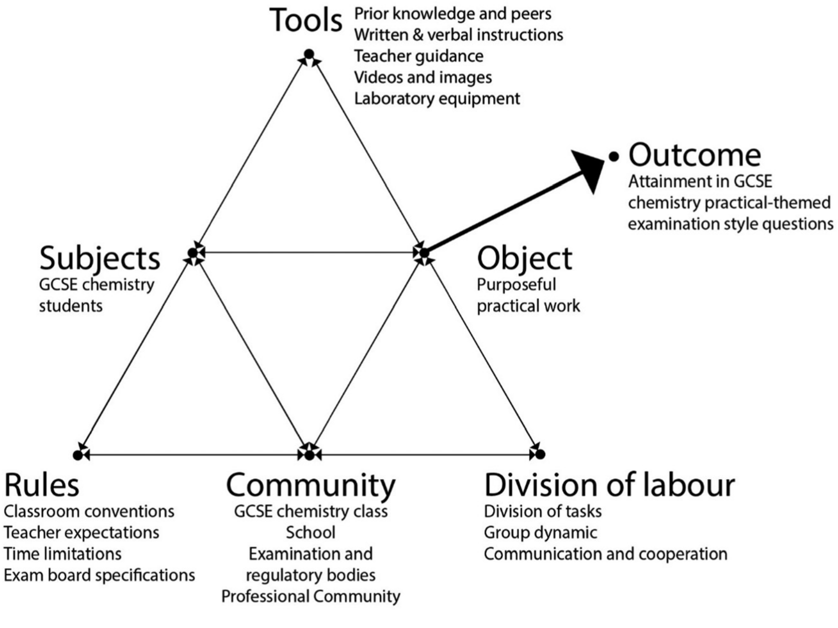


Fig. 1 The seven CHAT elements in an English GCSE chemistry practical activity system.

verbal instructions and visual images in practical videos or teacher demonstrations; and other people such as the teacher and fellow learners *via* scaffolding or ZPD. Although any one or more of the mediators in the activity system can be foregrounded, the rest remain indispensable to describe the methods and motives behind the subjects' transformations of the objects. This latter process is equivalent to learning, the mutual transformation of object and subject during practical activity (Leont'ev, 1978).

The rules refer to the explicit and implicit conventions and regulations that regulate the actions and interactions within the activity system (Engeström *et al.*, 2002) specifically laboratory conventions and teacher expectations. The community refers to individuals/groups who broadly share the same object and consider themselves distinct from other communities, which is a particular class of learners and their teacher within a particular school. The community is subject to the ideological values advocated by the Department for Education, and privileged in England's education system which is, arguably, a reflection of the Organisation for Economic Co-operation and Development (OECD, 2019) current globalised ideologies. Finally, the division of labour includes both the division of tasks between the members of the community and the vertical apex which embodies the division of power and status (Gifford and Finkelstein, 2020).

The interplay between the elements of an activity system can provide new opportunities for learning and for change (Engeström, 2001) and it is through interaction in a shared activity that the subject adjusts their thinking and behaviour to bring about a change (Bligh and Fathima, 2017).

Objectives and research questions

Recognising hands-on practical tasks as complex learning environments, this work draws upon cognitivism to inform novel instructional approaches designed to lower the cognitive load imposed on individual learners' working memories by the task. The novel instructional approaches includes pre-laboratory preparation videos "one video two voice over", in which procedural and conceptual information has been separated, and talk tasks "reverse storyboarding" designed to encourage learners to recall the procedure before carrying out the task. Cognitivism and sociocultural theory are employed to develop a cooperative learning environment by assigning the roles, "Lab Roles" to structure student–student interactions during the implementation of the task. As sociocultural theory emphasises the importance of talk as a mediating tool for the construction of knowledge, roles "Lab Talk" that scaffold student–student talk have also been introduced. Finally, the activity that results from these modifications is holistically addressed through the application of cultural historical activity theory (CHAT). CHAT is applied to this work to understand the interplay of factors that impact learners carrying out a practical task activity. Within the CHAT framework, we examine the impact that different instructional approaches have on the activity outcomes.

This work seeks to establish the use of cultural–historical activity theory (CHAT) as a framework for developing and implementing laboratory activities in chemistry education. The authors believe that the framework comprehensively identifies the interacting factors that impact the implementation and outcomes of hands-on practical tasks and is relevant to both high schools and postsecondary education. The study contributes to the existing knowledge of laboratory instruction by demonstrating the use of assigned roles to facilitate establishing a more equitable, cooperative, and inclusive learning environment.

Research questions

(1) Are there significant differences in summative test attainment scores between students exposed to Lab Talk and Lab Roles and their counterparts not exposed to this approach?

(2) What influence does the inclusion of one video two voice-overs have on students' perception of their learning experiences?

Context of the study

The students in this study attend an English academy for boys aged 11 to 18 in an area the Social Mobility Commission (2017) ranked 35th of the worst of the 324 areas of the country for social mobility for those from disadvantaged backgrounds. Students are given forecast grades for GCSEs based upon their Key Stage 2 (KS2) results from primary school (age 10 to 11 years). Targets are generated from each student's KS2 English reading and mathematics test attainment scores, their month of birth, and gender. National transition matrices derived from high-performing schools use this data to generate a minimum achievement grade (MAG) for each student for the end of Key Stage 4 (KS4) when the GCSE exam is taken. This MAG is the baseline from which stakeholders can judge if a student or a class has been successful.

Three GCSE chemistry groups within the same school, following the same course, and in the same year group were used for this study. However, each group was taught by a different experienced specialist chemistry teacher. Groupings are determined by course options and timetable considerations, each class has a 30 student capacity. The groups are composed of 30 males aged between 14 and 15 years old with MAGs ranging from 4 to 7, where the maximum grade achievable is 9. The groups have been named Control, Video, and Talk for this study. The average MAG for each group was calculated group; Control = 6.5, Video = 6.4, Talk = 6.1, which suggest that the groups have a similar average ability. The AQA exam board reported that in 2019 62.2% of students following the same course nationally gained a grade 6 or below (AQA, 2019b).

The work was conducted in compliance with the British Education Research Association ethical guidelines (BERA, 2018), aligning with the principles of informed consent, right to withdraw, and guarantee of anonymity. In this system, the school Headmaster acts as an overseer of all actions conducted in the school, and permission to complete this research was confirmed by him. This was followed by permission from relevant staff and students (student participants were over 13 years old). In seeking permission, students were informed about the research and their right not to participate, and to withdraw at any time. All data collected and used during this research was securely stored.

The activity triangle tools

At the beginning of a practical task, students are introduced to the equipment and procedures involved. Health and safety issues are discussed before they are allowed to proceed. This pre-laboratory introduction is usually made through either teacher demonstration, video, or a combination of the two. The nature of this pre-laboratory has developed in response to concerns about the efficacy of school practical work as a tool for learning (see Hennah, 2019 for a brief review). Enabling learners to become familiar with equipment and procedures before undertaking the activity aims to lower the cognitive load imposed by the task and so alleviate the students' 'mind-in-neutral' (Johnstone, 2006, p. 58) reliance on written instructions. Written instructions are also provided by a lab book that is only available to the students during the lesson as it is kept in school as evidence of practical work for the exam board.

Teacher demonstration

The teacher of the Talk Group habitually begins a practical task by discussing and demonstrating how to set up the equipment and carry out the task before the students carry out the task themselves. The *Temperature Changes* practical task was conducted in this habitual manner to afford the Talk Group with an experience that contrasted to the intervention tasks.

Video

As technology has developed there is an increasing interest in the use of multimedia as an instructional tool to teach science in schools (Higgins *et al.*, 2018). Videos, simulations, and written accounts of practical activities in textbooks and other written resources are used to supplement hands-on practical work or teacher demonstrations (Moore *et al.*, 2020).

Within this research setting, it has become increasingly common practice to replace a teacher demonstration with a video of the task and discussion immediately before the students carrying out the task themselves both the **Control** and **Video Group**s. The videos used by the **Control Group** instead of a teacher demonstration of the materials and methods were:

- *Making Salts* https://www.youtube.com/watch?v=FRaT0qOKZpU (4:40) and.
- *Electrolysis* https://youtu.be/pW8oBf-UCWQ (5:53).

For this study tailor-made videos showing each step of the procedure were produced for the *Making Salts* and *Electrolysis* practical tasks. Drawing upon CLT as previously described, particularly the Seery *et al.* (2019) recommendation that the two categories of knowledge required to understand and conduct a laboratory task are identified separately, a separate procedure voice over and concepts voice over were produced. In response to Johnstone's (2006) concerns outlined above, this approach affords learners with the opportunity to become accustomed to the practical activity and to consider separately what to do and why it is done.

The videos can be accessed as follows:

- *Making Salts* procedure https://www.youtube.com/watch?v=gShUaHxghsI (6:57)
- *Making Salts* concepts https://www.youtube.com/watch?v=7X6dCPIr2gI (6:26)
- *Electrolysis* procedure https://www.youtube.com/watch?v=xy3KmE-y5WQ (6:43)
- *Electrolysis* concepts https://www.youtube.com/watch?v=4GGcApT54gE (7:45)

Informed by instructional design for complex learning (van Merrienboer *et al.*, 2003) separating the information in this way could help to lower the cognitive load of the task. The procedural voice over video was watched before the hands-on task was carried out to prepare the students and the same video but with a procedural voice over was watched following completion of the task to aid reflection and understanding of the concepts that underlie the procedure.

To investigate the of efficacy these ''one video two voice over'' videos compared to the Control Group videos as an instructional approach they were watched by the Video Group. The Video Group watched the ''one video two voice over'' materials in the lesson immediately before and after the hands-on task.

The Talk Group were set the procedure video as a pre-laboratory home learning task (Agustian and Seery, 2017) to be watched prior to the practical lesson and the concept video was set as a home learning task to be completed before the following lesson. In this manner using the videos does not impact on the lesson time available for the practical task.

Lab books

Each student within the research setting is issued with a commercially available lab book (Quinn, 2018). However, the lab book is only made available to the students during the activity lessons. The lab book contains a written method and safety information alongside blank sections for recording data and answering follow-up questions. During practical work, the lab book may be used by the teacher to highlight health and safety issues and to discuss the written method. The same chemicals and laboratory equipment as detailed in the lab book are available to all three groups.

Hands-on practical tasks are completed within a 90 minute double lesson and a 45 minute single lesson in the same week is used to discuss the practical and for students to complete the lab book questions. A practical task is considered complete when the lab book activities have been finished and the teacher has provided feedback.

Reverse storyboarding

Storyboarding is a standard method for visual summarisation of shots in preproduction video whereas, reverse storyboarding is the term used to describe visual summarisation of existing video footage (Dony *et al.*, 2004). The Talk Group were asked to watch the ''one video two voice over'' procedure video as a home learning task to be completed before the practical lesson. The Talk Group were then asked to complete the reverse storyboard which summarised the procedure video and asked why that action was necessary. Using a storyboard in this way facilitates active learning which Barnes (2010) describes occurs through talk, whereby ideas are shared and shaped between interlocutors, forging links between new and existing knowledge to create common knowledge. Furthermore, the storyboard allows the students to share their understanding which can positively impact upon collaboration (Frith and Singer, 2008, p. 3876). The completed storyboard was checked by the teacher and then the students were issued with their lab books and allowed to complete the practical.

The activity triangle division of labour

Both the Control and Video Groups have teacher designed seating plans but are allowed to choose who they conduct practical work with. The Talk Group students were seated alphabetically and further organised into groups of three based on their seating position. Their teacher established and then maintained these groups beyond the confines of our data collection to all practical activities so they became accustomed to this style of working. Prior experience collaborating as a team can increase efficiency and performance and the number of transactional activities decreases, lessening the cognitive load experienced by established groups compared to *ad hoc* ones (Kirschner *et al.*, 2018). Changes from the generalised activity system (Fig. 1) incorporating these changes for the Talk and Video groups are shown in Fig. 2 for clarity.

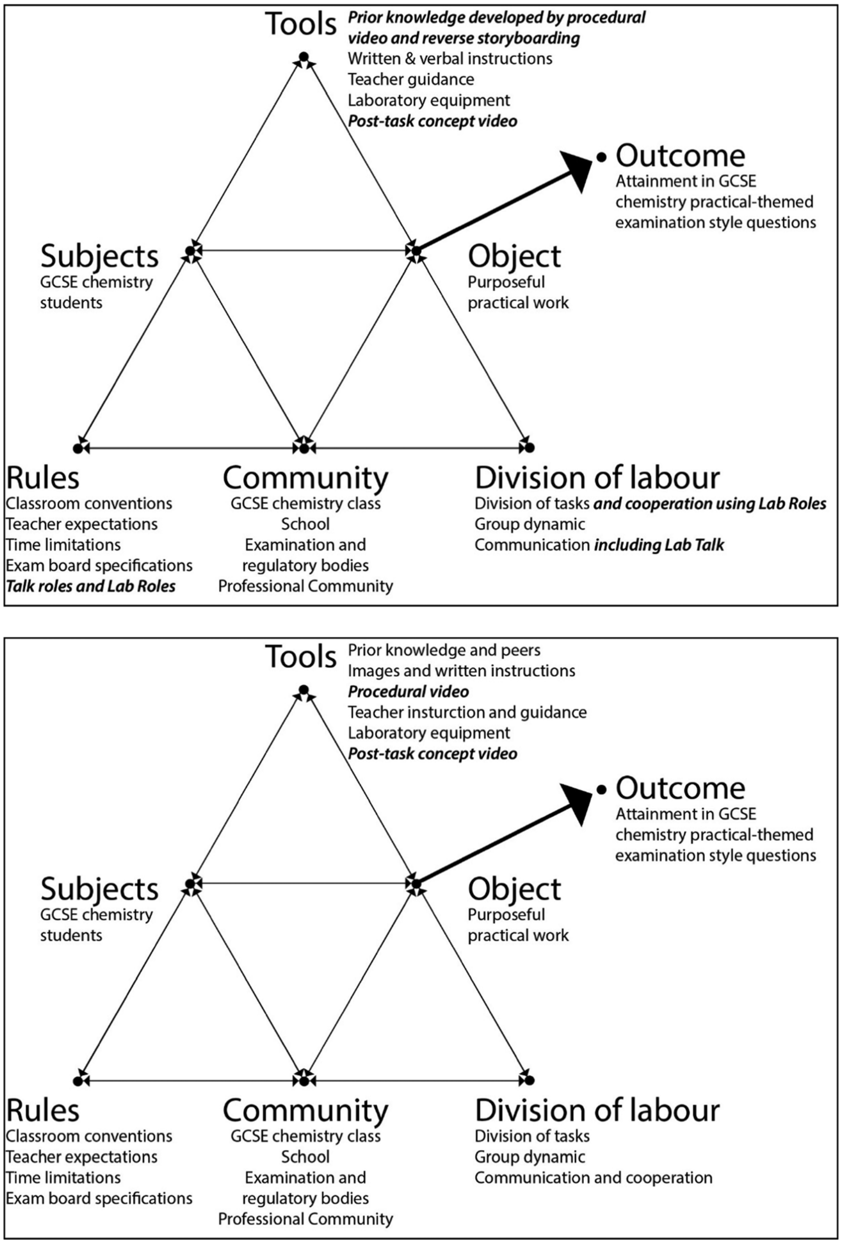


Fig. 2 The seven CHAT elements in our study, showing the Talk group (top) and Video group (bottom), with changes from the generalised activity system highlighted in bold italic.

Lab roles

Drawing upon Leikin and Zaslavsky (1999) and Fransen *et al.* (2011) as previously discussed, the Talk Group had been organised into groups of three and given lab roles for all their practical tasks so they were accustomed to this style of working. Grouping students as trios rather than pairs reduce issues caused by a group member being absent whilst still being a small enough grouping for everyone to be engaged. The roles delineate the contributions each member is expected to make (Gaunt and Stott, 2018) and were devised from those previously reported (Ott *et al.*, 2018). As shown in Fig. 3, the three lab roles were rotated within each group so that every student had experienced each role.

Lab talk

A great deal of work has been done to develop argumentation in chemistry education (see Erduran, 2019 for a comprehensive review) and the benefits of scaffolding younger learners' talk in science have been reported (Mercer *et al.*, 2004; Rojas-Drummond and Mercer, 2003). However, assigning specific talk roles and protocols to scaffold laboratory discussion has yet to be reported. Gaunt and Stott (2018) detail a range of talk roles and protocols from which Lab Talk has been developed. The same student trios are used for Lab Roles and Lab Talk. Fig. 4 illustrates the Talk Roles and protocol used during the reverse storyboarding activity. The students were encouraged to try to continue following this talk whilst conducting the practical activity.

Enforcing a structured division of labour by using lab roles and lab talk necessitates recognising that new rules are also being introduced as these practices are mandatory.

Methodology

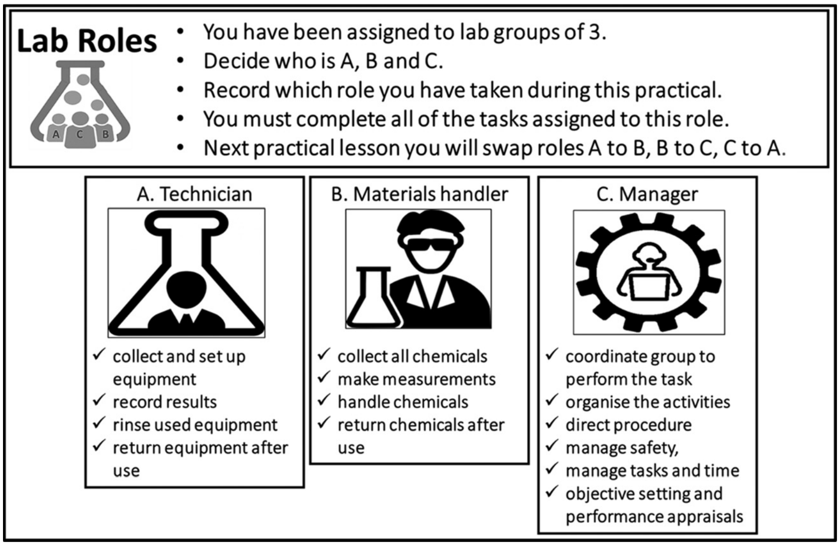
Drawing upon cognitivism and sociocultural theory, this work adopts a quasi-experimental design to investigate learning outcomes from GCSE chemistry practical tasks using a CHAT activity system. Engeström (2001) claimed that the interplay between the elements of an activity system can provide new opportunities for learning and for change. Here, changes to the English GCSE chemistry practical activity system's tools, division of labour, and rules are made and the resultant outcomes measured. Because learning, identity, and emotions are interdependent (Damasio, 1994; Wenger, 1998) affective data and student interview data have been collected.

Three GCSE curriculum practical tasks *Temperature Changes*, *Making Salts*, and *Electrolysis* (AQA, 2018) were selected for this study based upon their occurrence within the school calendar. Table 1 summaries the groups and the activities involved in this study.

Data collection

Quiz. The students from all three groups were given a paper quiz composed of practical-themed examination questions in the lesson immediately before beginning their practical task. The same quiz was administered to all three groups at the beginning of the chemistry lesson that immediately followed the practical task. This was done as a measure of student knowledge directly prior to, and following from the practical task. Although the quiz papers were anonymous students were asked to provide their MAG to facilitate data analysis. Quizzes belonging to students who were not taking part in the research were immediately disposed of.

All the student responses were collected together and marked blind using a matrix corresponding to the exam board mark scheme and examiner reports for the practical-themed examination questions used in the quizzes. Cohen's kappa was used to determine the agreement between the judgments k = 0.770 (95% CI, 0.564 to 0.975), $p < 0.0005$. Normality checks and Levene's test of homogeneity have been conducted on the participants involved in each test as a combination of absenteeism and students choosing not to return quiz responses has led to



Lab Roles

- You have been assigned to lab groups of 3.
- Decide who is A, B and C.
- Record which role you have taken during this practical.
- You must complete all of the tasks assigned to this role.
- Next practical lesson you will swap roles A to B, B to C, C to A.

A. Technician

- ✓ collect and set up equipment
- ✓ record results
- ✓ rinse used equipment
- ✓ return equipment after use

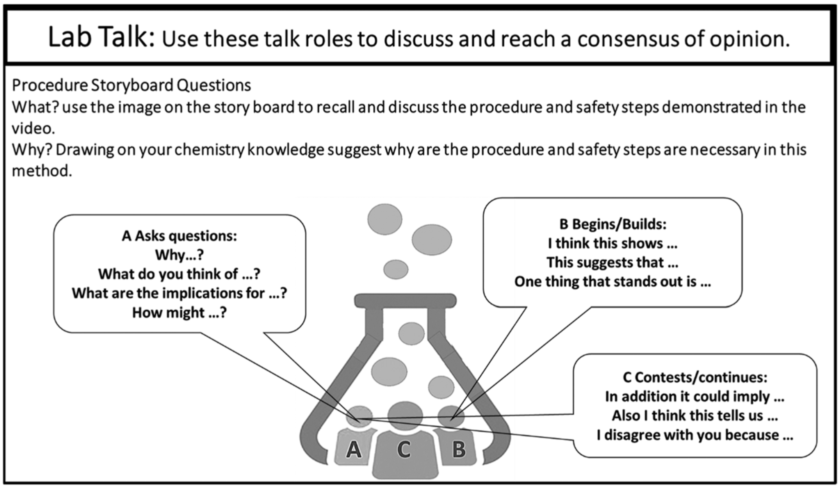
B. Materials handler

- ✓ collect all chemicals
- ✓ make measurements
- ✓ handle chemicals
- ✓ return chemicals after use

C. Manager

- ✓ coordinate group to perform the task
- ✓ organise the activities
- ✓ direct procedure
- ✓ manage safety,
- ✓ manage tasks and time
- ✓ objective setting and performance appraisals

Fig. 3 Talk Group lab roles and corresponding responsibilities during hands-on practical work.



Lab Talk: Use these talk roles to discuss and reach a consensus of opinion.

Procedure Storyboard Questions
What? use the image on the story board to recall and discuss the procedure and safety steps demonstrated in the video.
Why? Drawing on your chemistry knowledge suggest why are the procedure and safety steps are necessary in this method.

Fig. 4 Scaffolding the Talk Group's storyboard discussion using Talk Roles that correspond to their Lab Roles.

Table 1 A summary of the student groups, which hands-on practical tasks they have undertaken, and how they have been prepared for it

Group	GCSE chemistry practical task	Pre-laboratory home learning task	Hands-on lesson explication	Plenary task	Post-laboratory home learning task
Control	Making salts		Video		
Control	Electrolysis		Video		
Video	Making salts		Video (procedure)	Video (concepts)	
Video	Electrolysis		Video (procedure)	Video (concepts)	
Talk		Video (procedure)	Reverse storyboard		Video (concepts)
Talk		Video (procedure)	Reverse storyboard		Video (concepts)
Talk	Temperature changes		Teacher demonstration		

variations in the quantity of data gathered during each iteration (see Table 2).

Qualitative data. The three groups had completed the *Making Salts* and the *Electrolysis* practical tasks and a third practical task, *Temperature Changes*, before they were asked to complete the paper questionnaires. The purpose of the inclusion of a third practical task without ''one video two voice over'' videos, reverse storyboards nor roles was to provide the Video and Talk Groups with a comparable experience before responding to the questionnaire. The paper questionnaires belonging to students who were not taking part in the research were immediately disposed of.

Results

Research question 1. Are there significant differences in summative test attainment scores between students exposed to Lab Talk and Lab Roles and their counterparts not exposed to this approach?

Making salts quiz results. A one-way ANOVA was conducted to compare the Minimum Attainment Targets (MAG) of the three groups, Control 1 (n = 22), Control 2 (n = 22), Video 1 (n = 22), Video 2 (n = 25), Talk 1 (n = 24), Talk 2 (n = 29). Group names followed by a '1' indicate quiz results obtained before completing the practical task, while those followed by a '2' refer

Table 2 A summary of each group's video preparation and quiz data collection for the *Making Salts* and *Electrolysis* practical tasks

Group	Pre-laboratory home learning task	Practical lesson (90 min)	Post-laboratory home learning task	Following lesson (45 min)
Control		Video Quiz Practical task		Quiz
Video		Video (procedure) Quiz Practical task Video (concepts)		Quiz
Talk	Video (procedure)	Lab Talk Reverse storyboard Quiz Lab roles Practical task	Video (concepts)	Quiz

to the second iteration of the quiz which was taken in the chemistry lesson that immediately followed the practical activity. There was no statistically significant variance in the mean MAG between the groups [$F = 1.142$, $p = 0.341$]. Levene's test supports the null hypothesis that group variances are equal.

Making salt. Quiz attainment *z*-scores for each of the groups have been plotted as box plots (Fig. 5). A one-way ANOVA was conducted to compare the effectiveness of the three pedagogic approaches $F(5,135) = 43.035$, $p = 0.0005$. *Post hoc* tests using the Bonferroni correction revealed that *only* the Talk Group showed a statistically significant difference between their test *z*-score 1 and *z*-score 2 ($p = 0.0005$). The Talk Group performed significantly better on both tests than both the Control and Video Group ($p = 0.0005$).

Electrolysis quiz results. A one-way ANOVA was conducted to compare the Minimum Attainment Targets (MAG) of the three groups Control 1 ($n = 7$), Control 2 ($n = 18$), Video 1 ($n = 15$) Video 2 ($n = 25$) Talk 1 ($n = 19$) Talk 2 ($n = 21$), with group name convention as described above.

Normality checks and Levene's test of homogeneity were carried out and the assumptions were met. There was no statistically significant variance in the mean MAG between the groups [$F = 0.431$, $p = 0.826$] Levene's test supports the null hypothesis that group variances are equal.

Electrolysis. Attainment *z*-scores for each of the groups have been plotted as box plots (Fig. 6). A one-way ANOVA was conducted to compare the effectiveness of the three pedagogic approaches $F(5, 98) = 25.43$, $p = 0.0005$. *Post hoc* tests using the Bonferroni correction revealed that both the Video ($p = 0.008$) and Talk ($p = 0.0005$) showed statistically significant difference between their test *z*-score 1 and *z*-score 2 ($p = 0.0005$). The Talk Group performed significantly better on both tests than both the Control and Video Group ($p = 0.0005$).

Research question 2. What influence does the inclusion of one video two voice-overs have on students' perception of their learning experiences?

Questionnaire. Each of the Control, Video and Talk groups were issued with a questionnaire to complete following a third practical task – *Temperature Changes* – which was conducted without the use of "one video two voice over" videos, storyboards or laboratory roles, approximately four weeks after the completion of the *Electrolysis* task. The questionnaires were tailored to compare the students perceived practical task experience. All items are responded to on a Likert scale of 1–5, where 1 = Strongly Disagree and 5 = Strongly Agree. Each group had a questionnaire tailored to their experience and as such the reliability of each questionnaire was calculated separately. Reliability analysis was carried out on the Control Group's questionnaire responses comprising 12 items. Cronbach's alpha showed the questionnaire to reach acceptable reliability, $\alpha = 0.972$, Video Group's questionnaire comprising 26 items, $\alpha = 0.991$, and a reliability analysis was carried out on the Talk Group's questionnaire responses comprising 42 items, $\alpha = 0.995$.

The students' responses to the questionnaires have been grouped in the bar charts shown (Fig. 7 and 8), noting that a higher average indicates greater *agreement*. All three groups agreed that carrying out the *Making Salts* and *Electrolysis* practical tasks increased their understanding of the underlying scientific ideas. Both the Talk and Control Groups agreed that they feel confident about answering *Making Salts* and *Electrolysis* theory questions although the Talk Group showed the strongest agreement in each case. The Talk Group's scores in Fig. 5 and 6 support their confidence.

The greater confidence expressed by the Talk Group than the Video Group seen in Fig. 7 and 8 indicates that watching the video as a home learning task rather than immediately before carrying out the practical is beneficial. However, the Video

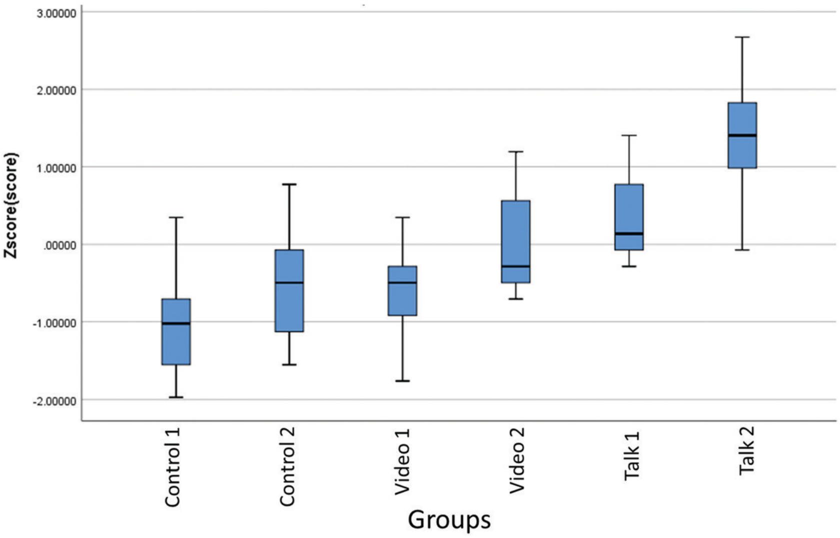


Fig. 5 *Z*-scores for student responses to the *Making Salts* practical-themed examination-style quiz questions. Where 1 following the group name refers to the quiz taken before the practical task and 2 refers to the quiz taken after the practical task.

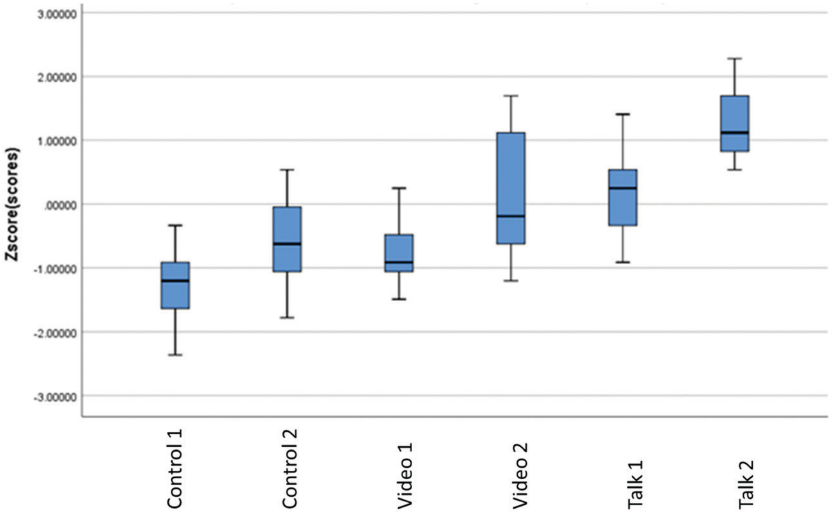


Fig. 6 *Z*-scores for student responses to the *Electrolysis* practical-themed examination-style quiz questions. Where 1 following the group name refers to the quiz taken before the practical task and 2 refers to the quiz taken after the practical task.

Group's scores may in part have resulted from the video's poor sound quality reported by their teacher when watching the videos in the lesson.

The average Likert scores presented in Fig. 9 demonstrate that having watched the ''one video two voice over'' videos for both the *Electrolysis* and *Making Salts* practical task has had a positive effect on the Talk Group students' confidence in learning. The Likert scores indicate that watching both versions of the video had the most positive effect on the students' confidence.

Discussion

In chemistry education research, university laboratory learning has been recognised as a ''complex learning environment'' (Seery *et al.*, 2019), which aims to guide use of instructional approaches designed to support student learning in this environment (van Merrienboer *et al.*, 2003). Purposeful practical work in the school laboratory, as previously discussed, is that which also facilitates the acquisition of complex cognitive skills. For this reason, adopting the strategies identified by Seery *et al.* should also be of benefit to schools. However, schools in England, are not free to set their chemistry examinations and associated curricula. Indeed, the assessment criteria of GCSE practical work and purposeful practical work appear to be a contradiction in terms. Existing research from cognitivism (Kirschner *et al.*, 2009; Kirschner *et al.*, 2011) and sociocultural theory (Rojas-Drummond and Mercer, 2003) both reported that student learning was improved when group activities, including laboratory tasks (Raviv *et al.*, 2019) were conducted collaboratively. CHAT enables all of these elements to be considered simultaneously as an activity system. Here, purposeful practical work was the activity's object and was be understood in terms of practical-themed exam style question outcomes. CHAT places thought and learning as products of social interaction in which tools are employed to facilitate learning and

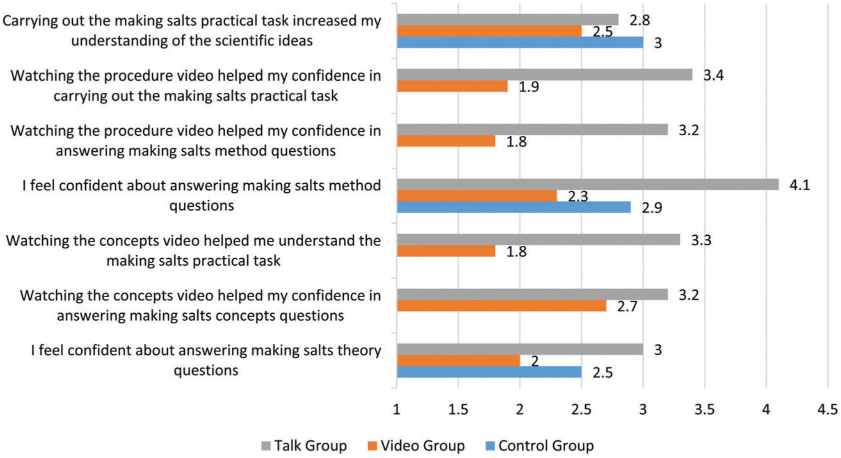


Fig. 7 Students' questionnaire responses to questions concerning *Making Salts* practical task (1 = Strongly Disagree; 5 = Strongly Agree).

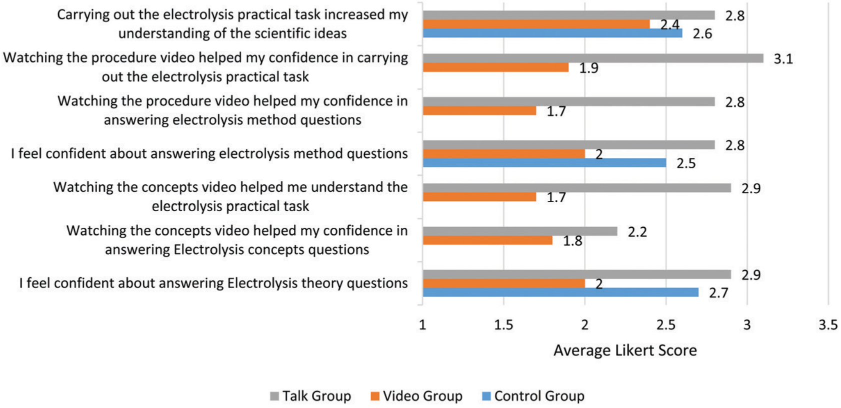


Fig. 8 Students' questionnaire responses to questions concerning *Electrolysis* practical task (1 = Strongly Disagree; 5 = Strongly Agree).

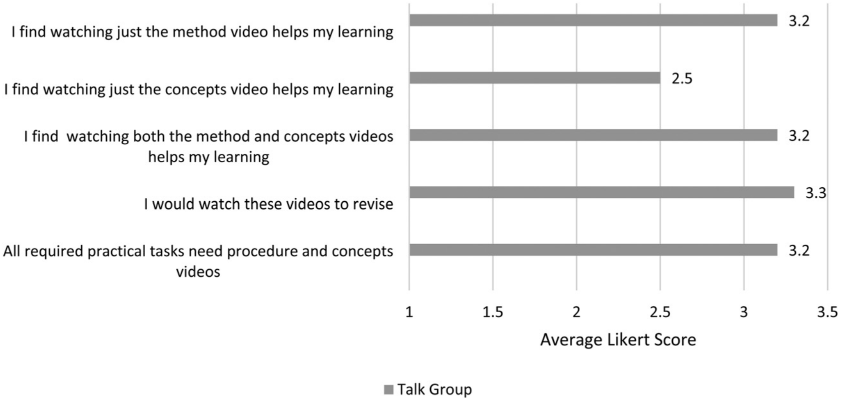


Fig. 9 Students' questionnaire responses to questions concerning the use of video in preparing for practical tasks and practical-themed exam questions (1 = Strongly disagree; 5 = Strongly Agree).

communication (Engeström, 2008). In doing so hands-on practical work becomes a dialogic process central to learning. Changes were made to the activity system adding the ''one video two voice over'' videos as tools designed to reduce the cognitive load imposed on an individual's working memory, and adding to the rules and division of labour within the group the mandatory Lab roles and Talk roles. The research questions described above were devised to investigate the impact of these changes on the activity system.

Research question 1

The first research question intended to explore whether there were significant differences in test attainment for students who engaged in Lab Talk and Lab roles, and between these groups and those students were not exposed to this approach. The number of students returning completed quizzes varied between quiz 1 and quiz 2 and between quiz groups suggesting some students may have only submitted one response. For this reason, a one-way ANOVA was conducted to compare the Minimum Attainment Targets (MAG) of the three groups for each iteration of the quiz to confirm that there was no statistically significant variance in the mean MAG between the groups.

Referring to the standard score box plots of group performance in *Making Salts* quiz 1 and 2 (Fig. 5) and *Electrolysis* quiz 1 and 2 (Fig. 6), the Talk Group performed better in the quizzes than either the Control or Video Groups and the lowest attainment scores were obtained by the Control Group. However, only the Talk Group performed statistically significantly better in quiz 2 than quiz 1 for both the *Making Salts* and *Electrolysis* tasks. Comparing the quiz 1 results for the three groups indicates that the ''one video two voice over'' procedure video watched by the Talk and Video Groups better prepared the students for the practical-themed exam questions than the Control Group's videos. Then comparing the Video and Talk Group average score for quiz 1 suggests that watching the procedure video in advance of the lesson followed by the reverse storyboarding activity using Talk roles better prepared the students for the practical-themed exam questions than just watching the procedure video. Comparing the three groups' quiz 2 results indicates that completing the practical task has improved their attainment in practical-themed exam questions. However, the differences in quiz 1 and quiz 2 attainment scores for the Control and Video Groups *Making Salts* task and the Control Group's *Electrolysis* task were not statistically significant. This may advocate that further intervention, beyond watching a concepts video, is necessary to produce a significant improvement in the practical-themed exam questions attainment. However, as the Talk Group's quiz 2 attainment scores improved with statistical significance compared to their quiz 1 scores for both practical tasks it is plausible that this may be attributed to the use of Lab roles during the practical task in combination with watching the ''one video two voice over'' concepts video after the lesson. Johnstone (2006) describes the role of pre-lab preparation plays in reducing the cognitive load imposed by the practical task, within the CHAT framework, this role is further extended to facilitate active learning (Barnes, 2010), and the construction of ''common knowledge'' (Frith and Singer, 2008, p. 3876) among group members. Furthermore, the reverse storyboarding activity provided an opportunity for the Talk group student trios to form the shared representation of the task needed for effective collaboration (Frith and Singer, 2008). The use of Lab Roles to impose a change the activities system's division of labour may also improve collaboration during the activity but it also changes the distribution of power and status as a particular student fulfilling a particular role becomes the most knowledgeable concerning that role and may have to share that knowledge so the group successfully complete the task.

The ''one video two voice over'' materials given as home learning activities and used in conjunction with Lab roles, reverse storyboards, and Talk roles produce the highest average attainment scores which suggest that scaffolding collaborative tasks and student talk further enhance the benefits provided by reducing the task cognitive load by separating the two types of knowledge needed for the activity. Further work would investigate each treatment separately to identify the greatest effect and to then apply this understanding to augment the impact of the concepts video.

The existence of a contradiction between the requirements of practical assessment and purposeful practical work is made visible by using the CHAT framework despite which, instructional adaptions informed by sociocultural theory and cognitivism have been shown to make statistically significant improvements to students' performance on practical-themed examination questions. The contradiction stems from the activity system's community element where the ideological values advocated by the Department for Education as represented by AQA and those advocated by scientists as represented by Gatsby foundation differ. Although teachers nor schools may change the assessment requirements of GCSE examinations, there is scope for the use formative assessment of school practical work prior to GCSE study. Furthermore, this work suggests that when learners understand the purpose of a practical task, they are better able to achieve the intended outcome whereas, purposeful practical activities have been defined in terms of the teacher knowing the purpose of the activity (Gatsby, 2017, p. 45) a point that could be addressed by the system's rules.

Research question 2

The second research question intended to explore the extent of influence of the ''one video two voice overs'' on students' perception of their learning experience and reported learning gains. The Video and Talk Group students' perception of their learning experiences and learning gains from the use of the ''one video two voice over materials are given in Fig. 7 and 8 which refer to the *Making Salts* and *Electrolysis* tasks respectively. Generally, the Talk Group reports greater confidence having watched the ''one video two voice over'' videos than the Video Group. This may be in part attributed to differences in the way the videos were watched. The Video Group watched the videos in the lesson whereas the Talk Group watched them outside of the lesson as a home learning task. It is not possible to distinguish between the effect of the less public environment or having more time to reflect on the procedure videos that have caused this increased confidence. It is interesting to observe that the Talk Group is less confident about the impact of the concepts videos than the procedure videos which may result from the absence of an active learning activity similar to the reverse storyboarding activity to accompany this video.

Students from all three groups indicate that practical task increases their confidence in answering practical-themed exam style questions. These results contrast with concerns raised earlier about the efficacy of practical tasks as learning tools. Indeed this work has presented several arguments in favour of the inclusion of hands-on tasks which include sociocultural consideration, embodied cognition and distributed attention model of working memory (Sepp *et al.*, 2019). It can also be observed that in every instance the Video Group reported a lower confidence value than the both the Control and Video Groups. For this reason it is logical to infer that additional factors not identified by this study are also having an impact on student confidence which provides scope for further study.

Referring to Fig. 9, the Talk Group report a greater confidence in the impact that the procedure video has on their learning than the concepts video. Investigating the students' perceptions of the impact of the concept video in conjunction with the development and implementation of the post-laboratory task offers scope for future work. The students also report that they are likely to watch the videos again when revising offers scope to investigate the design of revision videos for practical assessment through written examinations.

Conclusions

Cultural Historical Activity Theory has provided a useful framework for identifying interventions that could assist learners in carrying out purposeful practical work. Recognising the factors over which the classroom teacher has little or no control – that is the community – negates discussions about the purpose of the practical task accepting instead that task is directly linked to preparing the learner for their GCSE chemistry examination. Accepting the importance of the division of labour could disrupt existing divisions of power and status, and create more equitable activity as familiar teams take turns to adopt different Lab Roles and different Talk Roles. This, in turn, may positively impact student's identity and science capital. Making changes to the division of labour requires considering existing laboratory rules and how they need to be modified to incorporate such changes. The Talk Group report the most positive responses to the questionnaire which suggests that the interventions have resulted in a generally positive experience and their attainment data suggests that this positive experience has, in turn, produced positive results. Placing greater emphasis on how students talk during the activity as well as what they talk about by using storyboards recognises that education is a dialogic process and that language places emphasis upon is a ''cultural and psychological tool'' to accomplish an activity (Mercer, 2007, p. 137).

Limitations

A Quasi-Experimental Design was used to assess the effectiveness of the intervention without random assignment. Control and treatment groups were judged using their MAG rather than using pretest data and *z*-scores were used to compare like with like. However, the groups selected cannot always be guaranteed to be alike in all possible ways expected. The outcomes of the study may be affected by many other factors, for example an unanticipated event reduced the number of students available to participate in the Control Group's *Electrolysis* quiz 1. There will also be differences in how the activities are implemented such as the verbal instructions or how techniques are performed because each group is taught by a different teacher. To ameliorate these limitations, two practical tasks *Making Salts* and *Electrolysis* were used to increase the validity of the study so attainment could be compared between tasks as well as between groups.

Conflicts of interest

There are no conflicts to declare.

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Chapter 4: “What are they talking about?” A sociocultural linguistic approach to practical task effectiveness

<table>
<tr><td>Paper 4</td><td colspan="3">Hennah, N. (2023) “What are they talking about?” A sociocultural linguistic approach to practical task effectiveness. <i>Chemistry Education Research and Practice,</i> 24(2), 637–658</td></tr>
<tr><td>Author’s contribution</td><td colspan="3">A single author publication detailing work designed and carried out by the author alone.
Manuscript proofread by M.K. Seery</td></tr>
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West of Scotland Meeting for Teachers of Chemistry 2023 (Keynote)</td><td>0</td><td>4</td></tr>
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What circumstances led to Paper 4?

In Chapter 2, I described how my ontology had developed by engaging with practice-oriented research, similarly Chapter 3, explored my comprehension of practical tasks and here, I seek to demonstrate how my understanding of language has likewise been transformed.

The possession of language is the distinguishing feature of Homo sapiens to which our social structure, cultural enrichment, and creativity are attributed (Chomsky 1979). Language is the tool that we use to share and make sense of experiences, and experiences are transformed into knowledge and understanding using language (Mercer 1995).

Speech and language are not the same; speech is just one-way humans externalise language, but speaking is a generative process that solidifies thoughts into something concrete (Roth 2012). Studies in psychology have demonstrated that writing, reading, and listening impose differentially on working memory, and so writing is not recommended when the immediate recall of information is required (Tindle & Longstaff 2015).

My work emphasises oracy, the ability to express oneself in speech, as an educational tool because it is through talk that teachers and students are most able to work together on ideas and develop understandings (Hackling *et al.,* 2010). Oracy builds both familiarity with language, and cognition through social interaction. Furthermore, because speaking and listening are concurrent, the opportunity to provide feedback arises instantaneously.

In parallel to much of the research detailed in this thesis, I studied for a Master of Education in Applied Linguistics which developed my knowledge of sociocultural theory and the research methods employed within this paradigm. Adopting a Sociocultural linguistic approach (SCLA) acknowledges that knowledge is co-constructed by individuals in a social and cultural context through the medium of language (John-Steiner & Mahn 1996).

Science has a language with its own linguistic and rhetorical practices (Kuhn 2012) that can make learners feel alienated from the subject matter (Halliday 2006). Science also has a culture with its own perceptions, theories, aims, and material practices (Franklin 1995). Laboratory practices can encourage student participation and collaboration, but manipulation and gesture have also been observed to mediate the development of scientific language (Roth & Lawless 2002). Just as children begin to gesture before talking (Guidetti& Nicoladis 2008), providing opportunities for manipulation and gesture can bridge everyday language and the language of science (Roth & Lawless 2002).

From this perspective, hands-on tasks can be regarded as sites for both language learning and the acquisition of cultural practices, and so, manipulating laboratory equipment to scientifically observe phenomena is integral to the communication of science. From this understanding, practical work is an act of multimodal communication in which meaning making occurs through a variety of modes such as image, gesture, using artefacts and language (Flewitt 2011).

The research detailed in Papers 1 to 3; Chapters 1 to 3 employed interventions designed to encourage students to talk about laboratory procedures. This approach operationalised the assumption that student laboratory talk needed encouragement and improvement. Paper 4 describes the multimodal discourse that arises in the school laboratory without oracy intervention and seeks to address the following research questions by attending to both the teacher and the students' multimodal communication:

1. What kinds of opportunities do practical investigations afford students for learning the language of chemistry?
2. To what extent can student talk be used to determine a practical task's effectiveness as a site for communicating chemistry?

So, what new understandings came about from the work described in Paper 4?

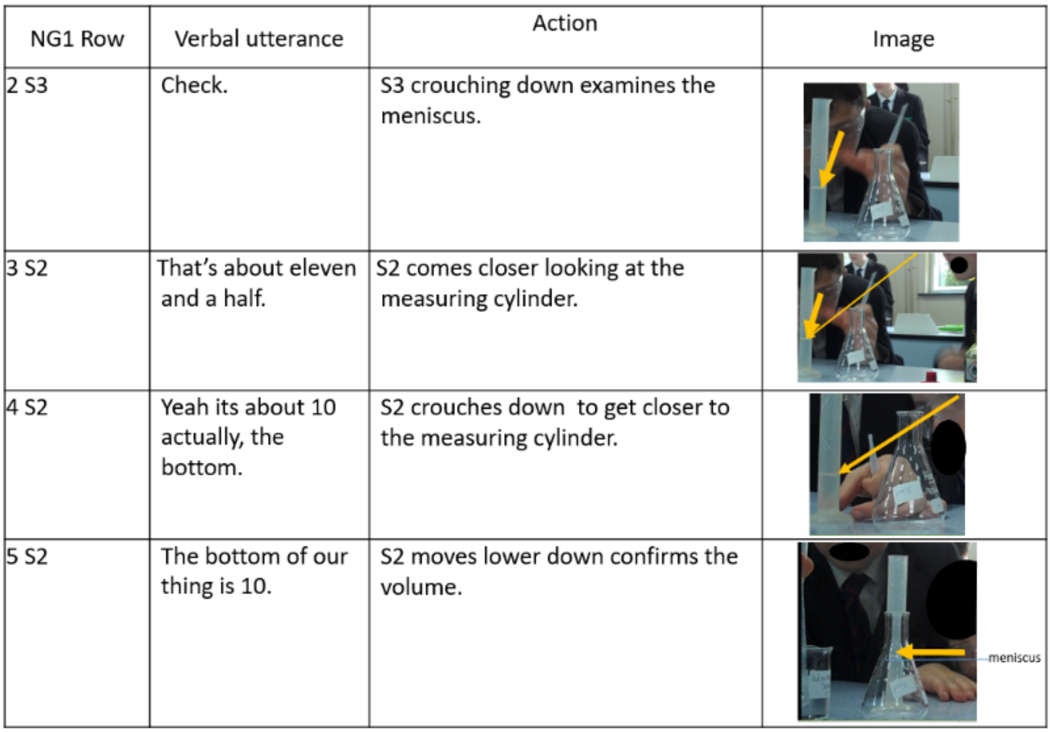
Multimodality has its origins in Halliday's description of the interdependent relationship between language and social context (Halliday 1978). It does not assume that language always plays a central role in communication nor denies that it often does (Flewitt 2011). For example, a student holding up a bottle and calling "this one?" cannot be understood by attending to speech alone. Attention must be given to both the spoken word and all the modes of meaning making employed by the students to reveal their thinking (Jewitt *et al*., 2001).

Prior to data collection, I made initial observations of the participating class which revealed a pattern to how the laboratory space was used, and that more than one camera would be required to capture the details of manipulating equipment. Observing the class and then trialling the camera set up prior to data collection provided a sense of what impact the camera's having. Obtaining an awareness of the researcher and cameras' impact in this way, helps to inform analysis (Nippert-Eng 2015) Repeating this process was advantageous in reducing the novelty of being filmed, the Hawthorne effect (Landsberger 1958).

Transcription is the academic practice of converting a social semiotic framework into a text or image and text for analysis. For example, a video recording may be transcribed into text and still image to identify the social values and positioning of the subject when a multimodal sign/s. As an artefact, the transcript is considered as empirical material (Bezemer & Kress 2008). In representing social interaction in transcripts, 'translations' are constantly made between modes, a process known as transduction (Bezemer & Mavers 2011).

The recordings had to be transcribed for analysis and having more than one camera recording provided the opportunity to clean the data: although inclusion, and omission are methodological concerns of transcription due to the volume of data recorded (Jewitt *et al*., 2001). Initially, the combination of watching the recordings and transcribing the dialogue afforded a deeper understanding of the communication taking place. Then, one sequences of interest were identified, I extended the transcription to include additional modes of meaning making.

A multimodal transcript from the neutralisation is presented Figure 4.1 and demonstrates students learning to accurately use a measuring cylinder. The students are taking turns to read the volume and reposition themselves to checking the reading. The transcript details the students' speech and describes their movements which is supported by including images snipped from the video footage. The direction of a student's gaze is represented by the arrows, but details of the context are lost by the need to maintain student anonymity.



NG1 Row	Verbal utterance	Action	Image
2 S3	Check.	S3 crouching down examines the meniscus.	
3 S2	That's about eleven and a half.	S2 comes closer looking at the measuring cylinder.	
4 S2	Yeah its about 10 actually, the bottom.	S2 crouches down to get closer to the measuring cylinder.	
5 S2	The bottom of our thing is 10.	S2 moves lower down confirms the volume.	

Figure 4.1, a multimodal transcription that demonstrates that the students have recognised the significance of viewing the meniscus at eye level as they can be seen to bend down towards the measuring cylinder before taking the measurement. The multimodal analysis was informed by Bezemer and Mavers (2011), Flewitt (2011), and Jewitt *et al*. (2001).

The purpose of this research was to understand the laboratory as a site for learning and using the language of science. Although the acculturation of students into the practices of science is interesting, the transcription in Figure 4.1 was not included in Paper 4. Perhaps one of the most difficult aspects of writing a research paper is understanding that not all the data and analysis carried out can usefully be included.

The analysed transcripts demonstrated that school chemistry practical lessons can be understood in terms of three linguistic opportunities: introducing, using, and reflecting upon language. I also demonstrated that multimodal discourse analysis could be used to assign the use of key words to the macroscopic, submicroscopic or symbolic level of thought. Furthermore, analysis of student dialogue revealed that the students' experimental results table structured their talk, and the detrimental effect of introducing novice learners to multiple levels of thought simultaneously.

Talk moves (discursive moves) "include those characteristics which any discourse must have in order to be coherent and sequential: without such sequential relationships there would not be a conversation but only a list of sentences" (Barnes & Todd 1977, p. 19). However, studies indicate that teachers lack theoretical tools and strategies for using classroom discourse to its best effect (Ruthven *et al*., 2017; Scott *et al*., 2006). Talk moves need to be made more explicit, 'visible and object-like' (Michaels & O'Connor 2015) so that teachers can reflect upon the use of specific talk moves and their relation to student learning.

Paper 4 reported a method for using talk moves to signpost learning in the domain of ideas and the domain of observables to gauge a practical task's effectiveness (Abrahams & Millar 2008) these are reproduced in Figure 4.2. Talk moves in conjunction with observation, could be used by teachers as a formative assessment of student learning to provide feedback and inform their teaching.

Exploratory Talk Moves in the Domain of Observables	
Level 1 Linguistic: what students do Talk as moves in the dialogue and in the content.	**Discursive moves**
	Qualifier
	Challenged
	Accepted
	Extended
Level 2 Cognitive: what students learn Talk as actions and thoughts.	**Action moves**
	Considering
	Questioning
	Engaging

Exploratory Talk Moves in the Domain of Ideas	
Level 1 Linguistic: what students do Talk as moves in the dialogue and in the content.	**Content moves**
	Evaluating results
	Meaning of a chemistry concept
Level 2 Cognitive: what students learn Talk as actions and thoughts.	**Purposive moves**
	Conceptual understanding
	Linking knowledge
	Building on each other's ideas
	Creating new knowledge

Figure 4.2 presents the hands-on and minds-on talk moves associated with students' learning in the laboratory.

What now for my professional practice?

The case study in Paper 4 demonstrates the multimodal communication that took-place during two acid and alkali practical lessons for learners aged 11 and 12 years. It was particularly important to understand the communication that takes place in a Key Stage 3 (KS3) practical lesson because there is greater flexibility for implementing changes when the lessons are less tightly bound to exam specifications. Indeed, as a direct result of this study the Science Department has made changes to to our KS3 provision so that a greater emphasis is placed on developing laboratory competencies.

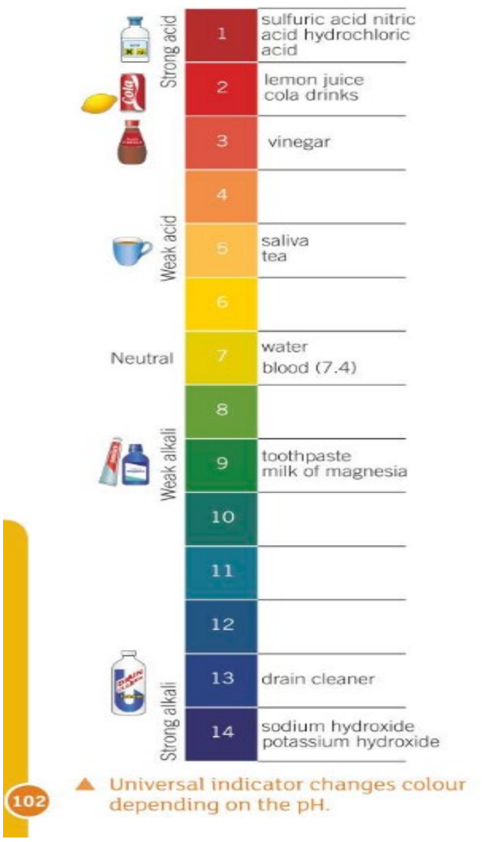


Figure 4.3, universal indicator chart from the textbook Activate 1 (Gardom Hulme *et al*., 2013)

The issues raised by this case study concerning the Acid and Base scheme of work have been addressed. References to ions in the scheme of work and assessments have been removed. There is now a greater awareness of introducing the miscomprehension of pH and strength. For example, Figure 4.3 appears in the Activate 1 textbook (Gardom Hulme *et al.,* 2013), labelling pH 1 as strong acid is problematic later when considering dilute solutions of strong acids. As not all colleagues share this concern so, it is likely to be left to individual choice whether this concern is addressed.

I have also introduced and shared several plenary talk activities so that our younger students become experienced using talk as a classroom tool for learning. One colleague has found using oracy plenaries to be very effective and has developed her own resources for the A level biology schemes of work.

The teacher observed in Paper 4 had reported that he is much more aware of his use of language particularly regarding moving between Johnstone's levels of thought (Johnstone 1982). He also reports that his involvement in this research has been of great personal benefit and refers to aspects of it when mentoring trainee teachers.

The insights provided by the work described in Paper 4 have helped me to plan my practical lessons, shown in Figure 4.4, so that I break down the practical task into the key words required to build a shared meaning of the task. I am also more aware of drawing on different levels of thought and try to stagger their introduction to lessen the cognitive load imposed on learners working memories.

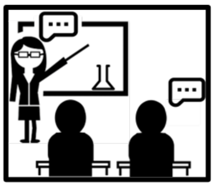
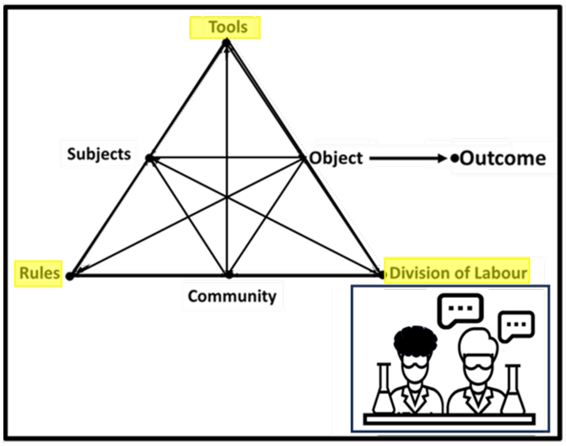
During the lesson	
Discussion and teacher demonstration to expose students to the subject's concepts, specialised vocabulary, and grammatical structures.	
Hands-on task arranged to disrupt the established norms. Students use of the language modelled by the teacher.	
Follow up discussion and questions. Teacher led metalinguistic work, thinking about the language used and how they are used.	

Figure 4.4 illustrates how my approach to practical lessons can be simply modified by recasting the school laboratory as a site for learning and using the language of chemistry. The descriptions highlighted in yellow facilitate planning a practical lesson to support students' disciplinary literacy.

Other professional impacts

I have delivered school-wide staff training on developing oracy and will be providing departmental training on how to consider laboratory lessons as language lessons and highlight the potential of the results table as a tool for talk.

It is a privilege to begiven the opportunity to share my work with teachers around the UK and Ireland, and I look forward to doing so again at the Scottish Initial Teacher Education Professional Learning Conference January 2024

Other professional impacts	**Audience**
Hennah, N. Research informed adaptations to school practical work *Chemistry in Action!* p. 32–35 [online] Available at https://www.cheminaction.com/files/ugd/7faa15d9ebe0ac823341c48c59347339b6e5c6.pdf	ChemEd Ireland attendees and Chemistry in Action! Magazine readers
Hennah, N. The ethical impact of science on society *Education in Chemistry* [online] 8 February 2023. Available at https://edu.rsc.org/ideas/help-your-students-understand-ethics-in-science/4016830.article	Education in Chemistry magazine readers
Freelance editor for BBC Bitesize KS3 chemistry curriculum materials and videos.	International usership

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Cite this: DOI: 10.1039/d2rp00233g

"What are they talking about?" A sociocultural linguistic approach to practical task effectiveness

Naomi Louise Hennah

This case study demonstrates teaching and learning activities in the school laboratory, and employs talk moves for the direct assessment of practical task effectiveness. By adopting a sociocultural linguistic approach (SCLA), learning chemistry is understood to be a discursive process in which knowledge is constructed through social interaction and language. Thus, learning may be identified by attending to the language used in classroom discourse. The multimodal communication that took place during two acid and alkali practical lessons for learners aged 11 and 12 years was filmed and transcribed. Analysis of the transcripts revealed the language learning opportunities afforded by the tasks and demonstrated that school chemistry practical lessons can be understood in terms of three linguistic opportunities: introducing, using, and reflecting upon language. This lesson structure could be employed to plan more inclusive and equitable practical lessons which foreground language and value discussion equally to manipulating equipment. Recasting practical lessons as sites for learning and using the language of chemistry, key words introduced by the teacher are tracked and counted throughout the lesson to identify when they are used and by whom. The novel 3-part practical (3P) framework and multimodal discourse analysis are employed to assign the use of key words to the macroscopic, submicroscopic or symbolic level of thought. This analysis reveals the centrality of a results table to structuring talk and the detrimental effect of introducing novice learners to multiple levels of thought simultaneously. The Talk Identification (ID) Grid has been developed and used here to analyse student group discourses using talk moves to signpost learning in the domain of ideas and the domain of observables. Descriptors are provided to support instructors in identifying talk moves and how these moves relate to practical task effectiveness to target interventions that improve learning procedural and conceptual knowledge in the laboratory.

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Introduction

Language is the principal medium through which teaching and learning occurs enabling learners to demonstrate their knowledge and understanding. Studies in chemistry education report that language is a barrier that impacts learning, participation, and attainment (Cassels and Johnstone, 1984; Byrne *et al.*, 1994; Markic, 2015; Markic and Childs 2016; Rees *et al.*, 2018, 2021).

There is an acknowledged understanding in education that all students are language learners, and all teachers are language teachers (Bullock, 1975; de Oliveira, 2016) many teachers do not feel able to provide language support in their lessons beyond teaching scientific vocabulary (Markic, 2015; Quílez, 2021). However, vocabulary alone is not enough; instead students need to learn both words and how to use them (semantic structures) if they are to make the same meaning as their teachers (Lemke, 1990). Recommendations for teaching science to English language learners include: providing opportunities for productive discourse and interactions with others; using multiple modalities; and engaging in disciplinary practices (National Academies of Sciences, Engineering, and Medicine, 2018). Such opportunities are provided by hands-on practical work when students are given the time to discuss their work, and to reflect upon their understanding of the pertinent scientific terms and concepts (Lemke, 1990; Tobin, 1990; Lunetta *et al.*, 2007; Abrahams and Reiss, 2012; Gatsby, 2017). This can be considered through the lens of sociocultural linguistics.

Sociocultural linguistics

Sociocultural linguistics is the broad interdisciplinary field concerned with the intersection of language, culture, and society, and encompasses sociolinguistics, linguistic anthropology, and linguistically oriented social psychology, among

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others (Gee, 2008). A sociocultural linguistic approach emphasises the importance of social interaction and language for thinking and learning (John-Steiner and Mahn, 1996).

Language and learning are inextricably linked (Halliday, 2004). Chemical concepts, as an example, do not exist in the abstract but are constructed by language blended with multimodal communication (O'Halloran, 2005, 2015; Gilbert, 2010), where multimodal is used here to refer to semiotic modes such as language, image, and gesture, rather than perceptual modes such as visual or haptic (Silliman *et al.*, 2018).

Understanding the centrality of language in chemistry education substantiates the adoption of sociocultural linguistic approach and the application of language teaching and learning approaches in school chemistry. Understanding is challenged through exploratory talk (educationally effective talk) creating new knowledge, facilitating students to work in their zone of proximal development (Vygotsky, 1978, p. 86). Student talk can be scaffolded using specific talk moves to develop discussion (Chin, 2006; Michaels and O'Connor, 2012). Scaffolds may be pre-planned macro-scaffolds or spontaneous micro-scaffolds (Nielsen and Hougaard, 2018). Talk moves are conceptualised as tools for facilitating academically productive talk (Michaels and O'Connor, 2015) and are used here to refer to talk occurring between teacher-student and student–student. Following from the work of Andersson and Enghag (2017), but in a school chemistry context, talk moves are conceptualised as tools that signpost how students talk during practical tasks. By identifying how students talk, targeted interventions may be implemented to better facilitate exploratory talk.

Language, cognition, and communicating chemistry

Language is conceived by Vygotsky as both a social instrument and a psychological tool (Mercer, 2002). Words and thoughts are inseparable, ''thought is not merely expressed in words: it comes into existence through them'' (Vygotsky, 1987, p. 219). Chemistry education requires ''multilevel thought'' (Johnstone, 1991 p.78), specifically three levels of thought which are often conceived as the apices of a triangle. These are the macroscopic (macro), observable and tangible phenomena that can be experienced with our senses; the submicroscopic (sub-micro), models of matter, atoms, molecules, ions, and structures that have descriptive or explanatory roles; and the symbolics which include all the chemical and mathematical signs and images used to represent chemical concepts (Johnstone, 1982; Johnstone, 1991; Talanquer, 2011).

To be successful, learners of chemistry must be able to make connections among these varied representations (Yore and Treagust, 2006), but teachers should focus on one level of thought at a time to secure students' understanding (Georgiadou and Tsaparlis, 2000; Tsaparlis *et al.*, 2010).

Cognitive load theory explains that all tasks place a demand on the participant's working memory (the intrinsic load), and when instruction draws on multiple levels of thought, a high (extraneous) load is also placed on the learner's working memory. The greater the extraneous cognitive load imposed, the fewer the cognitive resources available for dealing with intrinsic cognitive load and so less learning occurs (Sweller *et al.*, 2019).

The way information is presented during laboratory work is of particular importance, because the tasks themselves are demanding and impose a high cognitive load on the participants' working memory (Johnstone and Wham, 1979).

The purpose of hands-on practical work may be understood to link the domain of ideas and the domain of observables (Tiberghien, 2000). The domain of observables is used here to refer to procedural knowledge: what is done with objects; and making observations. In contrast, the domain of ideas considers conceptual knowledge: the theories; and ideas that underlie the activity. Student talk during laboratory work has been reported to focus on the procedures needed to carry out the experiment (Russell and Weaver, 2011; Sandi-Urena *et al.*, 2011), which suggests that learners are ''manipulating equipment and not ideas'' (Hofstein 2017, p. 366). The models presented by Tiberghien and Johnstone have been combined here (Fig. 1) to identify thinking by attending to talk that occurs during practical lessons.

Content and Language Integrated Learning is a language teaching approach that employs the target language for teaching and learning the subject matter (Dalton-Puffer *et al.*, 2010; Dalton-Puffer, 2011). In Content and Language Integrated Learning science education, a practical lesson is understood to be composed of three distinct parts, each of which provides distinct linguistic opportunities (Nikula, 2015). Firstly, the pre-experimental phase exposes students to the subject's concepts, specialised vocabulary, and grammatical structures. Next, the experimental phase affords learners the opportunity to use the language modelled by the teacher during the introduction. Finally, the post-experimental phase can include metalinguistic work, thinking about the language used and how it is used. Nikula's description of a three-part practical lesson and Fig. 1

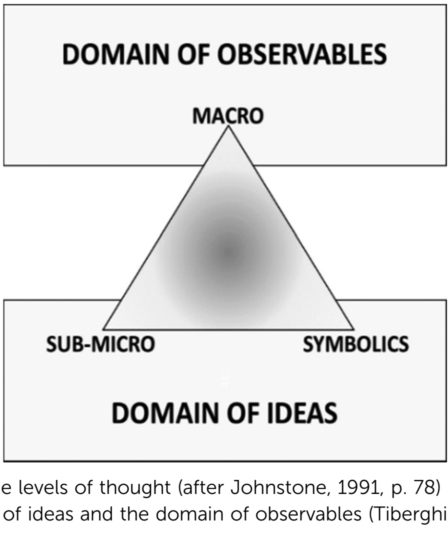
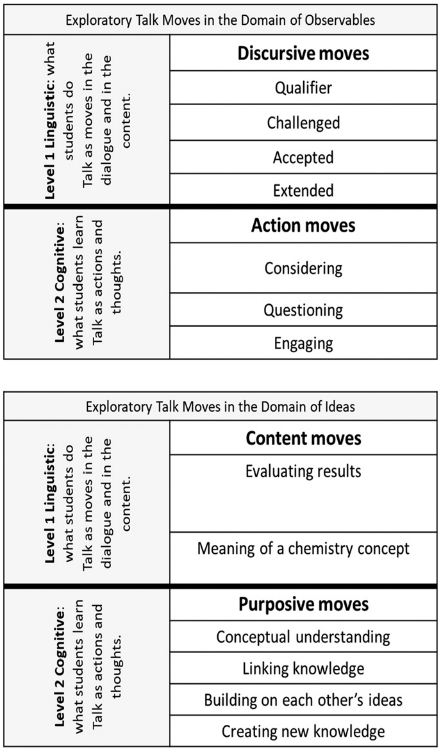


Fig. 1 Three levels of thought (after Johnstone, 1991, p. 78) aligned with the domain of ideas and the domain of observables (Tiberghien, 2000).

have been combined to develop the Three-Part Practical (3P) framework presented in Fig. 2.

The 3P framework operationalises key words (used here to refer to subject-specific language and symbolics) as markers that identify the domain and levels of thought being used during each part of the lesson. Multimodal data is required to contextualise the term, as for example, the word water could be used in talk concerning the procedure as a liquid at the macro level or in conceptual talk as a particle or molecule at the sub-micro level, and the meaning of H_2O at the symbolic level. However, when the word is spoken by a person holding a measuring cylinder, the macro level is implied. The 3P framework will be used to evidence whether both domains are referred to, and whether different levels of thought are drawn upon.

The 3P framework provides a temporal view of language use during the lesson: key words introduced by the teacher can be tracked through the lesson to see who is saying what, and when. Understanding science requires more than knowing and using key words; learners must also use the same pattern of meaning relations (semantic structures) as their teacher to make the same meaning (Lemke, 1982). When a learner can use key words in the pattern that is valued by the scientific community, they demonstrate understanding.



Exploratory Talk Moves in the Domain of Observables	
Level 1 Linguistic: what students do Talk as moves in the dialogue and in the content.	**Discursive moves**
	Qualifier
	Challenged
	Accepted
	Extended
Level 2 Cognitive: what students learn Talk as actions and thoughts.	**Action moves**
	Considering
	Questioning
	Engaging

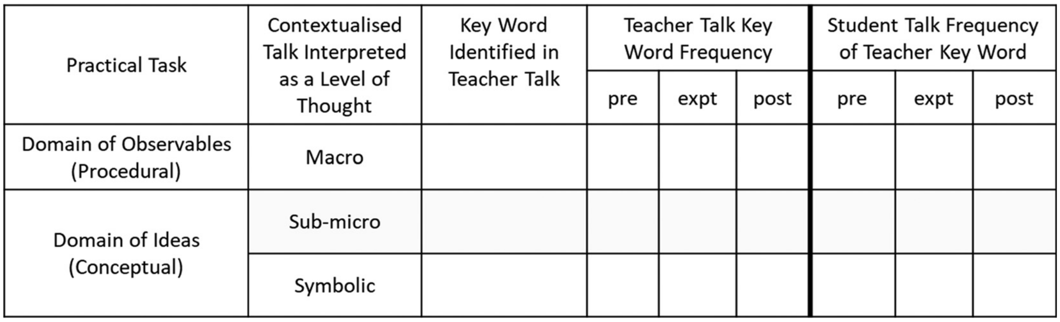
Exploratory Talk Moves in the Domain of Ideas	
Level 1 Linguistic: what students do Talk as moves in the dialogue and in the content.	**Content moves**
	Evaluating results
	Meaning of a chemistry concept
Level 2 Cognitive: what students learn Talk as actions and thoughts.	**Purposive moves**
	Conceptual understanding
	Linking knowledge
	Building on each other's ideas
	Creating new knowledge

Fig. 3 Talk ID Grid identifying exploratory talk moves in the domain of observables and in the domain of ideas at both level 1 linguistic, and level 2 cognitive to determine the effectiveness of a practical task for communicating (derived from Millar and Abrahams, 2009; Andersson and Enghag, 2017).

Identifying and assessing learning during practical work

An effective practical task facilitates doing and learning in both the conceptual domain of ideas and procedural domain of observables (Abrahams and Millar, 2008; Millar and Abrahams, 2009). The problem with trying to assess learning and understanding is that they cannot be directly observed but must be inferred from a learner's response to a task or question (Millar, 2013). However, analysis of talk has been proposed to understand how the interaction and content of students' communication is related to outcomes of their actions during physics practical tasks (Andersson and Enghag, 2017). As observation affords the direct assessment of students' practical skills (Reiss and Abrahams, 2015), attending to student talk during practical tasks provides the opportunity to directly assess learning. The direct assessment of learning is operationalised here using a version of Andersson and Enghag's (2017) model, adapted here for chemistry and combined with Millar and Abrahams' (2009) table clarifying the meaning of 'effectiveness' (p. 61). The resultant Talk Identification (ID) Grid and its component parts are available in the Appendix 1.

The exploratory talk moves shown in Fig. 3, the Talk ID Grid, are operationalised here as tools, or signposts, for identifying conceptual and procedural learning during the practical task. It is intended that the Talk ID Grid could be used as an assessment for learning (Black and Wiliam, 1998) tool to support teachers in the direct assessment of the effectiveness of a practical task as a site for communicating chemistry. The Talk ID Grid characterises talk moves so that chemistry



Practical Task	Contextualised Talk Interpreted as a Level of Thought	Key Word Identified in Teacher Talk	Teacher Talk Key Word Frequency			Student Talk Frequency of Teacher Key Word		
			pre	expt	post	pre	expt	post
Domain of Observables (Procedural)	Macro							
Domain of Ideas (Conceptual)	Sub-micro							
	Symbolic							

Fig. 2 The 3-Part Practical (3P) framework for learning the language of chemistry.

educators can target interventions that develop the quality of student talk and facilitate conceptual and procedural learning.

Purpose and research questions

This case study aims to contribute to the existing body of qualitative research concerning practical work in chemistry education by demonstrating how spoken language, within a multimodal context, may be employed to target interventions that develop teaching and learning. The following research questions (RQ) are addressed by attending to both the teacher and the students' multimodal communication:

1. What kinds of opportunities do practical investigations afford students for learning the language of chemistry?
2. To what extent can student talk be used to determine a practical task's effectiveness as a site for communicating chemistry?

Methodology of research

A case study design is adopted here that incorporates multimodal ethnographic principles to afford the in-depth examination of two practical activities in the acid and alkali chemistry unit of work for learners aged 11–12, in an English secondary school. This descriptive case study is a single case with embedded units (Yin, 2003) as the same class is observed during two different practical lessons and their language use compared. Furthermore, the case may be understood to be instrumental (Stake, 1995, as cited in Baxter and Jack, 2008) as student talk is used to assess practical task effectiveness. Adopting a SCLA understands that knowledge is co-constructed by individuals in a social and cultural context through the medium of language (John-Steiner and Mahn, 1996). Learning is mediated by language thus, analysing classroom talk provides a mechanism for directly identifying instances of learning. The unit of analysis is turns, where a turn is the time when a speaker is talking (Coulthard and Condlin, 2014). Modes in addition to talk will be foregrounded or backgrounded to facilitate understanding these turns (Sacks *et al.*, 1978).

Participants and recording

This work took place in an English Boys' Academy. One class of 30 students aged 11–12 years and their chemistry teacher were observed studying the acid and alkali chemistry topic. The researcher, who teaches in the same department, observed two additional lessons prior to data collection, to trial equipment, and familiarise the participants with the research process. Then, two full 90 minute practical lessons named Litmus and Neutralisation respectively were observed and recorded (lesson objectives and method are available in Appendix 2). The students had been assigned seats at the beginning of the school year and habitually worked in groups with students seated next to them. The room layout determined the camera locations which in turn determined which groups were filmed. The same two groups of three students were filmed during both lessons.

The video recordings were taken by four cameras, one focused on the front of the classroom where the teacher habitually stands and demonstrates, two on benches positioned where the student groups carry out their practical tasks, and one accompanying the researcher as field notes were taken and students were interviewed. In total more than 10 hours of recordings were made. The video recordings from the two lessons were categorised by camera location and were transcribed verbatim. The data was cleaned and triangulated by the researcher by repeatedly watching the recordings and comparing the transcripts from different cameras to each other and to the field notes. The written work produced by each group was also collected and used to support and validate data from the recordings in the absence of a second researcher.

To preserve anonymity, students habitually seated on the bench with camera 1 are referred to as Group 1 collectively and S followed by a number (S1, S2, and S3) individually. Students habitually seated on the bench with camera 2 are referred to as Group 2 collectively and S followed by a letter (SG, SK, and SL) individually. The teacher is coded as T, and class members not in Groups 1 and 2 are assigned the generic code S.

The work was conducted in compliance with the British Education Research Association ethical guidelines (BERA, 2018) and British Association for Applied Linguistics (2021), aligning with the principles of informed consent, right to withdraw, and guarantee of anonymity. The school Headmaster acts as an overseer of all actions conducted in the school, and permission to complete this research was confirmed by him. All data collected and used during this research was securely stored and although permission was granted by participants and their caregivers, and all the images used have been treated to prevent the identification of participants.

Multimodal discourse analysis

A SCLA to discourse analysis understands learning is produced in linguistic interactions that employ a range of modes to make meaning, and so learning may be identified through the analyses of these linguistic interactions. Within this approach teaching and learning a chemical concept for example, is understood in terms of teaching language through which the concept is formed and learning to use this language in the same way. The first RQ is addressed by multimodal discourse analysis to examine how meanings are made during practical work using the 3P framework.

An inductive thematic analysis as described by Ary *et al.* (2018) of the transcripts was conducted to expose language learning activities in each lesson part. Identification and coding of classroom strategies including initiation response feedback (IRF) questioning, were informed by Lemke's guide for recognising teacher and student strategies of control (1990, Appendix 2).

After identifying and classifying all the spoken episodes, the original recordings of sequences of interest were revisited. The transcription of these sequences was expanded to include a multimodal analysis of corresponding actions and images. The multimodal analysis was informed by Bezemer and Mavers (2011) and Flewitt (2011).

Word frequency analysis was used to understand students' language use in each of the three parts of the practical lesson using the 3P framework. Microsoft Excel was used for the transcription of talk from both practical lessons as demonstrated by Bree and Gallagher (2016). The discourse was separated into a turn per row of the spreadsheet and the search function was used to locate words of interest in the data. The key words were identified inductively through the transcription process. Once the term was located, the speaker and context were noted, and the frequency of use was calculated and tabulated in the 3P framework.

To address the second RQ, the transcripts of student-student dialogue as they perform the Litmus and Neutralisation lessons were deductively coded into one of three different talk types, disputational, cumulative, and exploratory talk (Mercer, 1995). Individualised decision making, and disagreement characterise disputational talk, the exchanges are short and composed of: assertions; counter assertions; competing; and defending. Cumulative talk is characterised by: instruction; repetition; confirmation; elaboration; and although positive, it is uncritical, so ideas are not challenged nor justified. In contrast, exploratory talk is both positive and challenging: criticism is both constructive and justified; opinions are sought, and joint decisions are made; everyone actively participates; the exchanges are longer and demonstrate reasoning.

The Talk ID Grid was then applied to assess the practical tasks' effectiveness as a site for communicating the language of chemistry. A task that facilitates exploratory talk is more effective than one that does not, however, the extent of a practical task's effectiveness (Abrahams and Millar, 2008; Millar and Abrahams, 2009) may also be determined using the talk moves associated with conceptual and procedural talk.

Results and analysis

RQ 1: What kinds of opportunities do practical investigations afford students for learning the language of chemistry?

Identification of language learning opportunities in each phase of the practical lesson

The video-recording transcripts from the two lessons were categorised as pre-experimental, experimental, and post-experimental, depending on the activity taking place. Inductive thematic analysis was then used to identify language learning activities consistent with those described in the Content and Language Integrated Learning science three-part practical lesson model (Nikula 2015). Extracts of the multimodal transcriptions are available in the Appendix 3 with brief salient excerpts from the datasets detailed below.

Pre-experimental phase

Extract 1 from the Litmus lesson begins with the teacher showing the students a piece of apparatus and initiating dialogue by asking the class a question. A student volunteers an answer to which the teacher gives feedback. This Initiation-response-feedback (IRF) strategy encourages multiple responses, facilitates productive thinking, (Sinclair and Coulthard, 1975), and provides ongoing assessment to assist students to construct knowledge (Chin, 2006).

Litmus lesson pre-experimental phase (from Extract 1)

Teacher: what is it? [row 7]

Student: is it, eh, is it an acid waffle or something like that? [row 8]

Teacher: Shush, good idea but no. [row 10]

Student: Pallet [row 13]

The students suggest names consistent with similar looking more familiar items like ''a pallet''. Through repeating the IRF sequence the teacher provides the students with time and opportunity to consider the apparatus directing his body and gaze to the student answering, and by doing so demonstrates that he values their suggestions. Barnes (2010), describes this process as ''active learning'' whereby ideas are shared and shaped between interlocutors, forging links between new and existing knowledge.

Extract 2 from the Neutralisation task also demonstrates language instruction, the students are exposed to key words (acid, alkali, neutral), both through the teacher's talk and a written procedure that is projected onto the board. Furthermore, the teacher's explanation of neutralisation has drawn upon the semiotics of chemistry (H^+, OH^-) in both the visible and auditory modes.

In the excerpt below, the teacher is standing next to the particle representations drawn on the board and is holding the conical flask containing the green neutral solution as he speaks.

Neutralisation lesson pre-experimental phase (from Extract 2)

Teacher: 23 drops boys, at this point it's neutral. [row 125]

Teacher: All the OH's have combined with the H's and made water, so in there now is just water. [row 126]

Teacher: Not acid not alkali because all the OHs and Hs have joined to make water. [row 127]

The teacher physically and verbally links the domains of observables and ideas, a ''contextualization of concepts'' (Jiménez-Aleixandre and Reigosa, 2006, p. 708). In doing the teacher is simultaneously drawing on all three levels of thought (Johnstone, 1991).

Experimental phase

The experimental phase of each lesson lasted approximately 40 minutes including the time required to pack away the equipment. Extract 3 is a transcription from the Litmus task which involves testing different solutions with red and blue litmus paper and recording and analysing the results in a table of results copied from the board.

The extract begins when Student 3 has just arrived and joins Group 1 as they begin testing their fourth solution, deionised water. In this excerpt, Student 2 directs Student 3 to test the solution first with red then blue litmus paper following the column sequence displayed in the results table.

Litmus lesson experimental phase (from Extract 3)

Student 2: litmus, red then blue. [row 136]

Student 3: Nothing happened, it's the same. [row 144]

Student 1: No change, it is not an alkali. [row 145]

When Student 3 reports the red litmus paper result to the group, Student 1 nods and then rephrases the observation in the manner previously modelled by the teacher. The student's talk and actions are directed by the results table, and they can express their observation using the teacher's language pattern.

The experimental phase of the Neutralisation lesson is noisy and unsettled. Extract 4 begins when Group 2 are adding sodium hydroxide solution dropwise to a conical flask containing hydrochloric acid and universal indicator. The student's need to count and record the number of drops added and the concomitant colour change.

Neutralisation lesson experimental phase (from Extract 4)

Student L: 20 [row 93]

Student K: 30 [row 94]

Student L: Oh yeah, write 30 turned orange. [row 95]

The students' language is indexical and dependent on the details of the practical task with very little use of subject-specific language and no consideration of what the results may mean. There appears to be a lack of collaboration as Student L dominates both the talk and equipment. These students do not appear to have adopted the language modelled by their teacher when introducing the neutralisation task.

Post-experimental phase

The teacher-led post-experimental phase lasted approximately 15 minutes for each task, additional time was provided at the end of each lesson for the students to check their written work and ensure the room was left clean and tidy. Extract 5 from the litmus task begins when Student K from Group 2 volunteers to provide the result for the mystery solution that smells like vinegar.

Litmus lesson post-experimental phase (from Extract 5)

Student K: In red litmus no change. [row 92]

Teacher: So, what does that tell us? [row 93]

Student K: That there wasn't, that it's not an [ac] alkali. [row 94]

Teacher: Good, it wasn't an alkali. [row 95]

Student K: Observation with blue litmus, it turned red so, it was an acid. [row 96]

The teacher has reinforced the requirement to test the solution with both red and blue litmus papers then record the results and analysis, by using an IRF sequence to model the language and thought pattern required to do so. The teacher gives verbal affirmation and repeats the student's analysis whilst recording the result in the table on the board. The feedback in this IRF sequence can be understood as a scaffold, specifically a spontaneous micro-scaffold, as the student is able to respond fluently with the next result and analysis.

In Extract 6 from the Neutralisation lesson, the teacher draws upon a range of modes to regulate difficulty and negotiate meaning during an IRF sequence.

Neutralisation lesson post-experimental phase (from Extract 6)

Teacher: If we're weakly acidic what are we going to have more of? [row 14]

Student: H plus. [row 15]

Teacher: Yeah, we're still going to have more H plus aren't we. [row 16]

Teacher: I'm going to put extra H plus, just to mean that there is not as many as the excess H plus in the strong acid. [row 17]

The teacher uses gesture to draw the student's attention toward the particle diagram on the board to scaffold his question and the student successfully negotiates the teacher's meaning. Having elicited the student's response, the teacher then marks the importance of the point by confirming and then rephrasing the answer (Lemke, 1990).

Furthermore, the teacher critically reflects on language and engages in metalinguistic work by writing and talking about his choice of terms "extra" and "excess" to denote a change in magnitude.

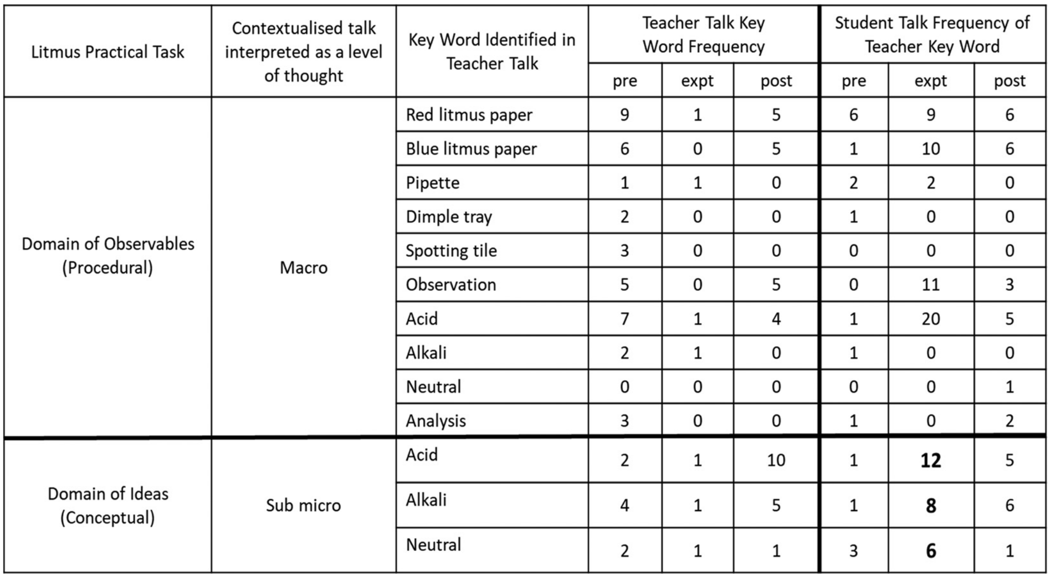
In summary, although the Litmus and Neutralisation lessons were not planned as language lessons, there is evidence that the teacher and the students are involved with language teaching and learning activities consistent with the Content and Language Integrated Learning science three-part practical lesson model (Nikula, 2015).

Tracking the introduction and uptake of key words

Inductive thematic analysis was used to identify the key words introduced by the teacher in the pre-experimental phase of the lesson. These terms were then used to deductively analyse the full transcripts from the lessons. The frequency with which participants used these terms in each part of the lesson was calculated and tabulated for the Litmus lesson (Fig. 4) and Neutralisation lesson (Fig. 5). Incomplete terms such as, red used to refer to red litmus paper, have not been counted in the word frequency table.

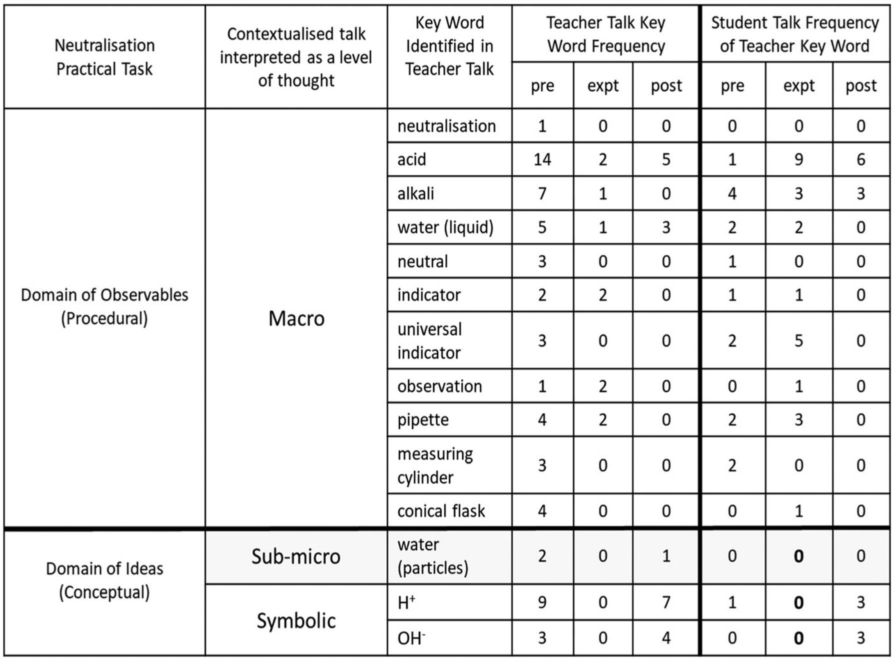
The frequency of key word use shown in Fig. 4 and 5 indicate that teacher talk dominates the pre-and post-experimental phases of the lessons. As previously demonstrated in the pre- and post-experimental phase Litmus and Neutralisation lesson exerts above, the teacher controlled the talk by selecting respondents one at a time, whereas during the experimental phase up to six students were talking, thus the word frequency values increased. The use of the word acid for example, is used by Student 1 in the Litmus lesson experimental phase (Extract 3) and by two other students in the Litmus lesson post-experimental phase (Extract 5). However, it is not always possible to assign the use of a word to a particular student during group interaction.

The Litmus lesson data presented in Fig. 4 shows an increase in frequency of students using key words from the pre-experimental phase to the post-experimental phase which may indicate that the practical task has increased students' familiarity and confidence in using the terms as learning to



Litmus Practical Task	Contextualised talk interpreted as a level of thought	Key Word Identified in Teacher Talk	Teacher Talk Key Word Frequency			Student Talk Frequency of Teacher Key Word		
			pre	expt	post	pre	expt	post
Domain of Observables (Procedural)	Macro	Red litmus paper	9	1	5	6	9	6
		Blue litmus paper	6	0	5	1	10	6
		Pipette	1	1	0	2	2	0
		Dimple tray	2	0	0	1	0	0
		Spotting tile	3	0	0	0	0	0
		Observation	5	0	5	0	11	3
		Acid	7	1	4	1	20	5
		Alkali	2	1	0	1	0	0
		Neutral	0	0	0	0	0	1
		Analysis	3	0	0	1	0	2
Domain of Ideas (Conceptual)	Sub micro	Acid	2	1	10	1	**12**	5
		Alkali	4	1	5	1	**8**	6
		Neutral	2	1	1	3	**6**	1

Fig. 4 Litmus Task 3P Framework of key word frequency use during each phase of the lesson demonstrates that the students are working in the domains of observables and ideas.



Neutralisation Practical Task	Contextualised talk interpreted as a level of thought	Key Word Identified in Teacher Talk	Teacher Talk Key Word Frequency			Student Talk Frequency of Teacher Key Word		
			pre	expt	post	pre	expt	post
Domain of Observables (Procedural)	Macro	neutralisation	1	0	0	0	0	0
		acid	14	2	5	1	9	6
		alkali	7	1	0	4	3	3
		water (liquid)	5	1	3	2	2	0
		neutral	3	0	0	1	0	0
		indicator	2	2	0	1	1	0
		universal indicator	3	0	0	2	5	0
		observation	1	2	0	0	1	0
		pipette	4	2	0	2	3	0
		measuring cylinder	3	0	0	2	0	0
		conical flask	4	0	0	0	1	0
Domain of Ideas (Conceptual)	Sub-micro	water (particles)	2	0	1	0	**0**	0
	Symbolic	H^+	9	0	7	1	**0**	3
		OH^-	3	0	4	0	**0**	3

Fig. 5 Neutralisation Task 3P Framework of key word frequency use during each phase of the lesson demonstrates that the students are not working in the domain of ideas.

apply words correctly facilitates understanding their meaning (Toulmin, 1972).

The Litmus lesson (Fig. 4) demonstrates 78 incidences of key terms being used by the students during the experimental phase but only 25 are recorded during the Neutralisation lesson (Fig. 5). These results indicate that the Neutralisation task is less effective than the Litmus task at facilitating students to adopt the language modelled by their teacher during the pre-experimental phase. For example, Fig. 5 records one incidence of a student using the word neutral, which in occurred during the Neutralisation lesson pre-experimental phase (Extract 2, row 124).

Identifying the key word use in both domains and at different levels of thought

Multimodal data recorded in the transcripts was employed to provide the context in which a key word was being used. In

Fig. 4 from the Litmus lesson, the word acid was coded to both the domain of observables and the domain of ideas, corresponding to the macro and sub-micro levels of thought respectively. For example, in the post-experimental phase litmus excerpt above (from Extract 5), Student K states ''Observation with blue litmus it turned red, so it is an acid.'' The word acid is coded here in the domain of ideas because the student is drawing a conclusion based on the observation that the litmus has changed colour. In this context the word acid is understood to correspond to the submicroscopic level of thought although there is no explicit reference to ''acid particles'' there is an implicit suggestion that this solution is in some way different to a solution that does not produce a colour change.

Comparing Fig. 4 and 5 demonstrates that student talk in the domain of ideas occurs more often during the Litmus lesson (values shown in bold) specifically, there are 26 occurrences compared to zero during the Neutralisation lesson.

In Fig. 5, the teacher is recorded using symbolics during both the pre- and post-experimental phases of the Neutralisation lesson, whereas there is no evidence of students doing so during the experimental phase. In the Neutralisation lesson post-experimental phase excerpt (from Extract 6), the teacher provided a micro-scaffold for Student 1 to respond, ''H plus''. This is likely to be indexical as there is no evidence to suggest that hydrogen ions nor the submicroscopic Arrhenius model of acids is understood.

Using the 3P framework to identify problematic communication

Using multiple levels of thought places an increased demand on the learners working memory which may impede learning (Johnstone, 1991). Comparing Fig. 4 and 5, only the Neutralisation lesson draws on all three levels of thought which may mean that the language used during this lesson places a greater demand on the learner's working memory than the language used during the Litmus lesson. As the students were not recorded working in the domain of ideas during the experimental phase of the Neutralisation lesson, this assumption seems probable. If increasing the demand on students' working memory impedes learning, then the language used to present the Neutralisation lesson imposes a greater barrier to learning than the language used to present the Litmus lesson. It has been reported that students struggle to make the intended meaning when presented with multiple levels of thought, students may not make sense of them in the way the teacher intended (see for example, Lin and Chiu, 2010) thus, the potential for misunderstanding is also increased. The analysis using the 3P framework identifies three issues with the instructional communication used in the Neutralisation lesson.

Firstly, in the post-experimental phase excerpt (from Extract 6), the teacher repeatedly refers to ''H plus'', as an oral abbreviation of hydrogen ions. In doing so, the teacher is implicitly moving between the submicroscopic and symbolic levels of thought. Instruction that moves between multiple levels of thought increases the extraneous cognitive load placed on the learner's working memory to the detriment of learning (Milenković *et al.*, 2014).

Secondly, colour is a semiotic mode used to convey meaning (Pantaleo, 2012) the particle models drawn on the board (reproduced in Extracts 2 and 6) show the hydrogen ion in blue and hydroxide ion in blue and red. An expert will recognise that the hydrogen nucleus is common to both ions and be able to decode the teacher's meaning, but it may be distracting for a novice and add to the extrinsic cognitive load Miller *et al.* (2019).

Finally, in the pre-experimental phase excerpt (from Extract 2) the teacher states, ''All the OHs have combined with all the Hs and made water...'' and ''Not acid, not alkali because all the OHs and Hs have joined to make water'' in which the ellipsis of H^+ to H and OH^- to OH has occurred. Ellipsis is defined as the deletion of linguistic elements that can be understood from contextual clues (Bussmann *et al.*, 2006), here; the contextual clues are derived from the multimodal data available to the students. However, the resultant terms are incorrect and the unconscientious modelling of imprecise language compounds the difficulty in learning chemistry. If a learner's understanding of scientific language can be facilitated by combining the appropriate everyday language with scientific language (Rees *et al.*, 2021) then resorting to the use of symbolics as an oral shorthand may be avoided.

The teacher's use of problematic language during the neutralisation lesson can be related to the commercially available course and assessment materials used by the school. These materials require 11 and 12 year-olds to represent neutralisation as the symbol equation for the formation of water from hydroxide ions and hydrogen ions (Gardom Hulme *et al.*, 2013). This requirement disrupts curriculum coherence (Gardner *et al.* 2014) as the particle model and atoms are new ideas for the young learners, whereas ions and the Arrhenius model of acids are met in the 14–16 year-old's curriculum (UK Government, 2014). The ellipsis may have arisen because the teacher is avoiding introducing and discussing ions and charges, thus symbols and part-symbols are used without acknowledging the Arrhenius definitions underlying submicroscopic ideas. The ellipsis and the use of verbal shorthand indicate that both learning and teaching difficulties arise when knowledge is presented in steps (Danili and Reid, 2004) that disrupt the hierarchical sequence of scientific ideas (McPhail, 2021).

Outcomes from the application of the 3P Framework

Key words introduced by the teacher were tracked and counted throughout each phase of the lesson making the students' up take of this language visible. The language used during the Litmus and Neutralisation lessons was compared using the 3P framework (Fig. 2) and the following observations were made:

- There were fewer incidences of learners using the language introduced by the teacher during the Neutralisation lesson
- None of the language associated with the domain of ideas was used by students in the experimental phase of the Neutralisation lesson

- Only the Neutralisation lesson used chemical symbols and drew on all three levels of thought

The analysis of the students' language use during the Litmus lesson indicates that the learners have assimilated the language modelled by the teacher as both the key words and the pattern in which they were used were evident in the experimental phase.

RQ 2: To what extent can student talk be used to determine a practical task's effectiveness as a site for communicating chemistry?

The experimental phase for each lesson lasted approximately 40 minutes. Transcripts of student talk during the hands-on practical tasks were deductively coded into sequences corresponding to Mercer's (1995) typology of talk. Most of the student–student talk coded as cumulative; an example of which is provided in the excerpt below.

Litmus lesson experimental phase cumulative talk (from Extract 7)

Student 1: I'm doing the next one [row 44]
Student 2: You need to write it turns red [row 45]
Student 1: I have [row 46]
Student 1: No, I haven't [row 47]
Student 2: You get the water thing and I'll get litmus [row 48]

The student interaction is positive but there is a lack of discussion which results in a series of parallel statements rather than dialogue. Extract 7 and the cumulative talk moves described by the Talk ID Grid are available in Appendix 4.

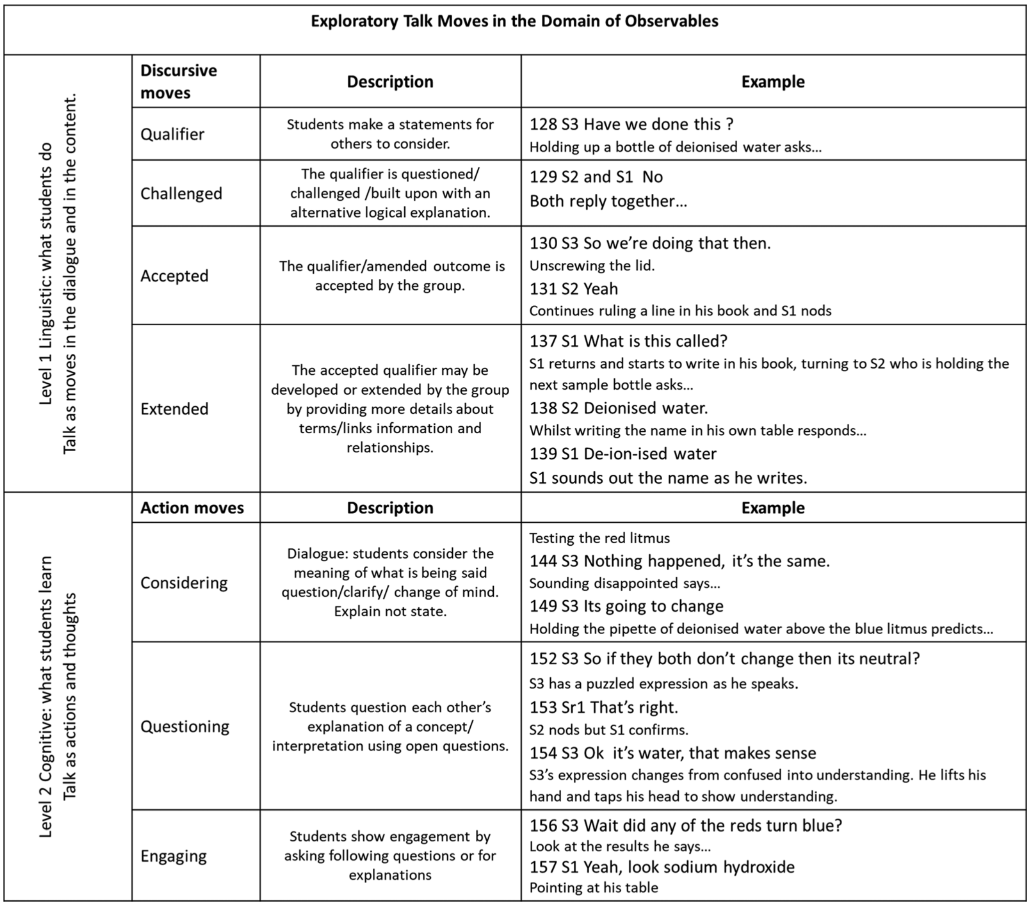
There was only one instance of disputational talk identified from the transcripts, an example of which is provided in the excerpt below.

Litmus lesson experimental phase disputational talk (from Extract 8)

Student G Stop! [row 80]
Student G Write it down first [row 81]
Student L So blue no change [row 82]
Student G What you've already done it? [row 83]
Student G When we weren't looking? [row 84]

The excerpt indicates competition within the group and individualised decision making rather than consensus. Extract 8 and the disputational talk moves described by the Talk ID Grid are available in Appendix 5.

One talk sequence from Group 1 during the Litmus task (Extract 3) was coded as exploratory talk as: the students were constructively critical of each other's ideas; and worked together to collect and analyse their data. This exploratory talk sequence was then deductively coded into the four



Exploratory Talk Moves in the Domain of Observables

	Discursive moves	Description	Example
Level 1 Linguistic: what students do Talk as moves in the dialogue and in the content.	Qualifier	Students make a statements for others to consider.	128 S3 Have we done this ? Holding up a bottle of deionised water asks…
	Challenged	The qualifier is questioned/ challenged /built upon with an alternative logical explanation.	129 S2 and S1 No Both reply together…
	Accepted	The qualifier/amended outcome is accepted by the group.	130 S3 So we're doing that then. Unscrewing the lid. 131 S2 Yeah Continues ruling a line in his book and S1 nods
	Extended	The accepted qualifier may be developed or extended by the group by providing more details about terms/links information and relationships.	137 S1 What is this called? S1 returns and starts to write in his book, turning to S2 who is holding the next sample bottle asks… 138 S2 Deionised water. Whilst writing the name in his own table responds… 139 S1 De-ion-ised water S1 sounds out the name as he writes.
Level 2 Cognitive: what students learn Talk as actions and thoughts	Action moves	Description	Example
	Considering	Dialogue: students consider the meaning of what is being said question/clarify/ change of mind. Explain not state.	Testing the red litmus 144 S3 Nothing happened, it's the same. Sounding disappointed says… 149 S3 Its going to change Holding the pipette of deionised water above the blue litmus predicts…
	Questioning	Students question each other's explanation of a concept/ interpretation using open questions.	152 S3 So if they both don't change then its neutral? S3 has a puzzled expression as he speaks. 153 Sr1 That's right. S2 nods but S1 confirms. 154 S3 Ok it's water, that makes sense S3's expression changes from confused into understanding. He lifts his hand and taps his head to show understanding.
	Engaging	Students show engagement by asking following questions or for explanations	156 S3 Wait did any of the reds turn blue? Look at the results he says… 157 S1 Yeah, look sodium hydroxide Pointing at his table

Fig. 6 Exploratory talk moves in the domain of observables in which: discursive moves characterise the manner in which students work together; and action moves which describe how students engage with each other's ideas.

quadrates of the Talk ID Grid which has been divided for clarity into Fig. 5, the domain of observables and Fig. 6, domain of ideas.

The exploratory talk moves in domain of observables

The discursive moves in Fig. 5 indicate that the group has agreed that latecomer Student 3 can carry out the next test. The communication begins when Student 3 asks ''Have we done this?'' and establishes himself as a member of the group by using the inclusive pronoun ''we''. The discourse moves in Fig. 5 at level 1 demonstrate that the group has entered dialogue, listening to, and responding to each other to reach the common goal of collecting results.

The level 2 exploratory talk action moves in the domain of observables reveal that Student 3 is both carrying out the practical task, and is actively considering the result's meaning by asking "So if they both don't change then it has to be neutral?" Student 1 affirms and shares the data in his table of results to justify his response. These action moves indicate that the group are constructing knowledge and understanding of their actions in a process of active learning that may facilitate recall of the activity later.

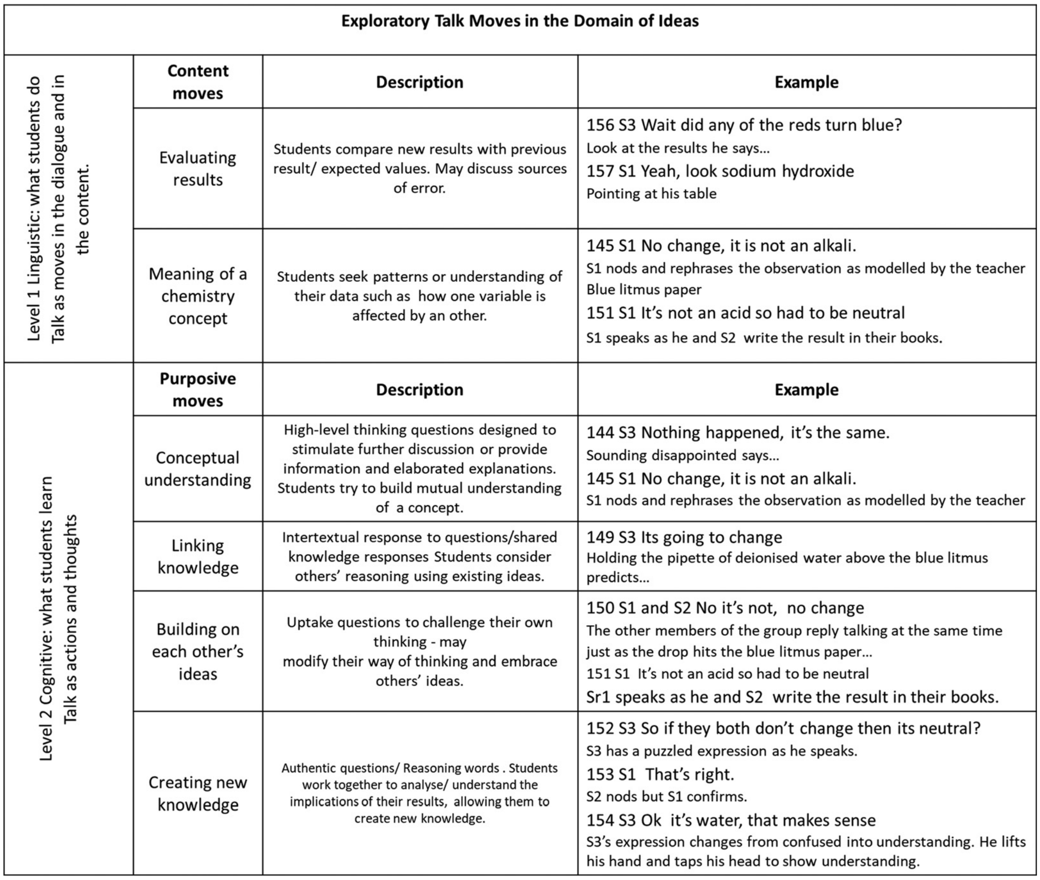
The exploratory talk moves in domain of ideas

Fig. 7 level 1 content moves suggest that the students understand that testing with both red and blue litmus paper is necessary as Student 1 reports ''No change, it is not an alkali'' rather than suggesting it must be an acid. Furthermore, there is evidence of evaluation when Student 3 asks ''Wait did any of the reds turn blue?'' which Student 1 affirms and evidences his response by sharing his results table and names sodium hydroxide solution. The learners are seen to be focused on both collecting and interpreting results as they work. Analysis of the discussion reveals that the students are developing a shared understanding of the underlying concepts.

The Level 2 purpose moves in the domain of ideas (Fig. 7) demonstrate how common knowledge has been constructed through the negotiation of the meaning of the experiment results. The exchange culminates when Student 3 states "Ok it's water, that makes sense." aligning this new knowledge with his prior knowledge by recognising that deionised water, like tap water, must be neutral. Thus, Student 3 conveys his thinking through talk, and demonstrates that the analysis of the result has been internalised as, learning chemistry requires integration of the scientific viewpoint with existing ideas (Scott *et al.*, 2011) suggesting that he will still be able to demonstrate this understanding later.

Outcomes from the application of the Talk ID Grid

Using the Talk ID Grid to identify and understand exploratory talk moves provides evidence of the students drawing on procedural



Exploratory Talk Moves in the Domain of Ideas

	Content moves	**Description**	**Example**
Level 1 Linguistic: what students do Talk as moves in the dialogue and in the content.	Evaluating results	Students compare new results with previous result/ expected values. May discuss sources of error.	156 S3 Wait did any of the reds turn blue? Look at the results he says… 157 S1 Yeah, look sodium hydroxide Pointing at his table
	Meaning of a chemistry concept	Students seek patterns or understanding of their data such as how one variable is affected by an other.	145 S1 No change, it is not an alkali. S1 nods and rephrases the observation as modelled by the teacher Blue litmus paper 151 S1 It's not an acid so had to be neutral S1 speaks as he and S2 write the result in their books.
Level 2 Cognitive: what students learn Talk as actions and thoughts	**Purposive moves**	**Description**	**Example**
	Conceptual understanding	High-level thinking questions designed to stimulate further discussion or provide information and elaborated explanations. Students try to build mutual understanding of a concept.	144 S3 Nothing happened, it's the same. Sounding disappointed says… 145 S1 No change, it is not an alkali. S1 nods and rephrases the observation as modelled by the teacher
	Linking knowledge	Intertextual response to questions/shared knowledge responses Students consider others' reasoning using existing ideas.	149 S3 Its going to change Holding the pipette of deionised water above the blue litmus predicts…
	Building on each other's ideas	Uptake questions to challenge their own thinking - may modify their way of thinking and embrace others' ideas.	150 S1 and S2 No it's not, no change The other members of the group reply talking at the same time just as the drop hits the blue litmus paper… 151 S1 It's not an acid so had to be neutral Sr1 speaks as he and S2 write the result in their books.
	Creating new knowledge	Authentic questions/ Reasoning words . Students work together to analyse/ understand the implications of their results, allowing them to create new knowledge.	152 S3 So if they both don't change then its neutral? S3 has a puzzled expression as he speaks. 153 S1 That's right. S2 nods but S1 confirms. 154 S3 Ok it's water, that makes sense S3's expression changes from confused into understanding. He lifts his hand and taps his head to show understanding.

Fig. 7 Exploratory talk moves in the domain of ideas in which: content moves characterise students' analysis of data; and purpose moves which describe how the students think together to understand their data.

and conceptual knowledge by working in both domains. The domain of observables is evidenced by students working collaboratively to collect the results required to complete the task. Whereas the students working in the domain of ideas is evidenced as the group build a shared understanding of the results.

Group 1 also used cumulative talk during the Litmus task, and it was the late arrival of Student 3 that triggered the change to exploratory talk. In Extract 3, Student 3 is showing interest and engagement with the Litmus task, but he is also accepted and supported by Student 1 and Student 2 and; it is this combination that facilitates collaboration and exploratory talk.

Fig. 7 the domain of ideas, documents Student 3 looking at his partner's results and asking, "So if they both don't change it has to be neutral?" This initiates an extended talk sequence where the more knowledgeable partners help Student 3 construct new knowledge. From this perspective, the results table is performing a new role beyond dictating what is recorded to orchestrating dialogue.

Implications

The multimodal discourse analysis in this case study revealed that the two practical chemistry lessons observed provided three distinct linguistic opportunities. Firstly, during the pre-experimental phase the teacher introduced concepts and key words. Then, the student-centred experimental phase afforded learners the opportunity to use the teacher's language. Finally, the teacher-orchestrated post-experimental phase afforded deliberation and metalinguistic work. Developing language learning opportunities to support all students is an inclusive and equitable approach to facilitating learning in the laboratory.

The 3P framework could be used to plan practical lessons in which: key words and language patterns are foregrounded; and problematic language identified. Further, the lesson structure affords time for: student discussion during the practical task; and for discussion between the teacher and students when the hands-on activity is completed.

Patterns of language used by both the teacher and the students, replicated the structure of the results table. Understanding that a table of results may impact student talk, affords educators with the opportunity to decide in advance what they want the students to talk about and design the table accordingly. In this way, the teacher may regard the results table as a macro-scaffold for student talk (Nielsen and Hougaard, 2018).

The analysis of a sequence of exploratory talk using the Talk ID Grid, demonstrated the talk moves associated with an effective practical task. The Talk ID Grid operationalises talk moves as signposts of conceptual and procedural learning during practical work. This could help teachers to identify learning from student–student talk and to intervene when required with spontaneous micro-scaffolds such as repeating, revoicing, or questioning (Chin, 2006; Michaels and O'Connor, 2012, 2015; Nielsen and Hougaard, 2018).

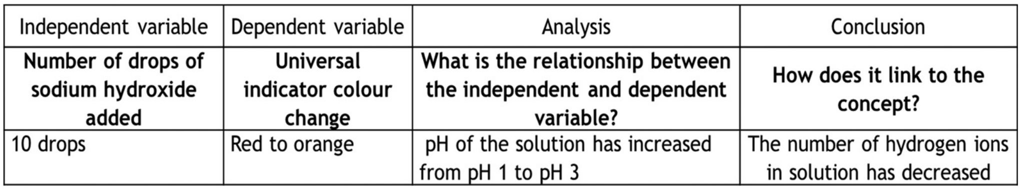
Direct assessment is part of most teaching episodes: scanning the room to see if the task is complete; checking laboratory equipment is being used safely; listening to tones of voice; and noting body language in case someone needs help. Similarly, student talk moves described in the Talk ID Grid (available in the Appendix 1) could be used to indicate that a group needs help managing collaboration or discussion. As teachers become more familiar with the range of talk moves identified in the Talk ID Grid, the moves could be employed as signposts for assessment for learning (Black and Wiliam, 1998). For example, the Talk ID Grid could be used to classify group talk during a practical task to identify aspects of the intended learning that need to be reinforced in subsequent lessons. In addition, targeted modifications to the practical task could be devised to make future iterations more effective as a site for communicating chemistry.

Further work

Identifying the features of effective talk during a practical task provides an entry point for designing macro-scaffolds that facilitate the desired moves. The content and purposive moves associated with the domain of ideas in Fig. 7 were observed when students were completing the analysis column in the Litmus task table of results. Investigating the efficacy of the results table as a macro-scaffold offers scope for further work. The impact on student talk of including: 1, a column designed to initiate discussion of data such as, how one variable is affected by another, and 2, a column designed to stimulate reasoning about and discussion of the implication of their result could be investigated. Fig. 8 provides an example of how a results table designed as a macro-scaffold for student talk during the Neutralisation task may be constructed.

The discursive and action moves associated with the domain of observables shown in Fig. 6, relate to the ways the students are interacting whilst carrying out the practical task. During this episode of exploratory talk, the students were working collaboratively (Kirschner *et al.*, 2009) to create common knowledge. Adopting protocols such as Lab Roles and Lab Talk, as described in our earlier work (Hennah *et al.*, 2022), could facilitate more episodes of collaboration and exploratory talk during future iterations.

Research has shown that formal and explicit instruction in collaborative skills is requisite for classroom collaboration to occur (Le *et al.*, 2018). The co-occurrence of collaboration and exploratory talk observed in this case study is of interest, as



Independent variable	Dependent variable	Analysis	Conclusion
Number of drops of sodium hydroxide added	**Universal indicator colour change**	**What is the relationship between the independent and dependent variable?**	**How does it link to the concept?**
10 drops	Red to orange	pH of the solution has increased from pH 1 to pH 3	The number of hydrogen ions in solution has decreased

Fig. 8 An example of a possible Neutralisation task results table designed to be a student talk macro-scaffold.

approaches known to facilitate collaboration may also stimulate exploratory talk.

Conclusion

This work has demonstrated mechanisms by which the laboratory may be recast as a site for teaching and learning the language of chemistry. Using the 3P framework to plan and deliver practical lessons would ensure that the time and opportunity are provided for learners to discuss and build an understanding of the task and its underlying chemical concepts. The resultant student talk may in turn be evaluated using the Talk ID Grid. The relationship between academic success, vocabulary, literacy skills, and social mobility has long been apparent (Hart and Risley, 2003) which, in conjunction with changing population profiles, suggests the need for a greater focus on language in chemistry education. It is hoped that this work will provide colleagues with tools and support to help do so in the laboratory.

Limitations

As a small-scale case study, the generalisability of any conclusions is very limited due to the specificity of the case. Further, the qualitative methods employed here are subjective; transcription is a transduction as semiotic material is moved from one mode to another and reflects both the research aims and directs the research findings. Although, data was cleaned by the researcher repeatedly watching the recordings and comparing the transcripts with field notes and the learners written work, validation by a second experienced researcher would further secure the outcomes. Furthermore, unconscious bias must also be acknowledged, particularly as the researcher also teaches chemistry in the same school.

The study and the frameworks presented were designed by a teacher who, motivated by an apparent language barrier in teaching and learning chemistry, sought to understand language, and learning in practical lessons. In doing so, future interventions could be targeted to better support learning in the context of the school chemistry laboratory observed, however, the study may also be useful to other educators, and researchers seeking to foster the quality of student talk and collaboration.

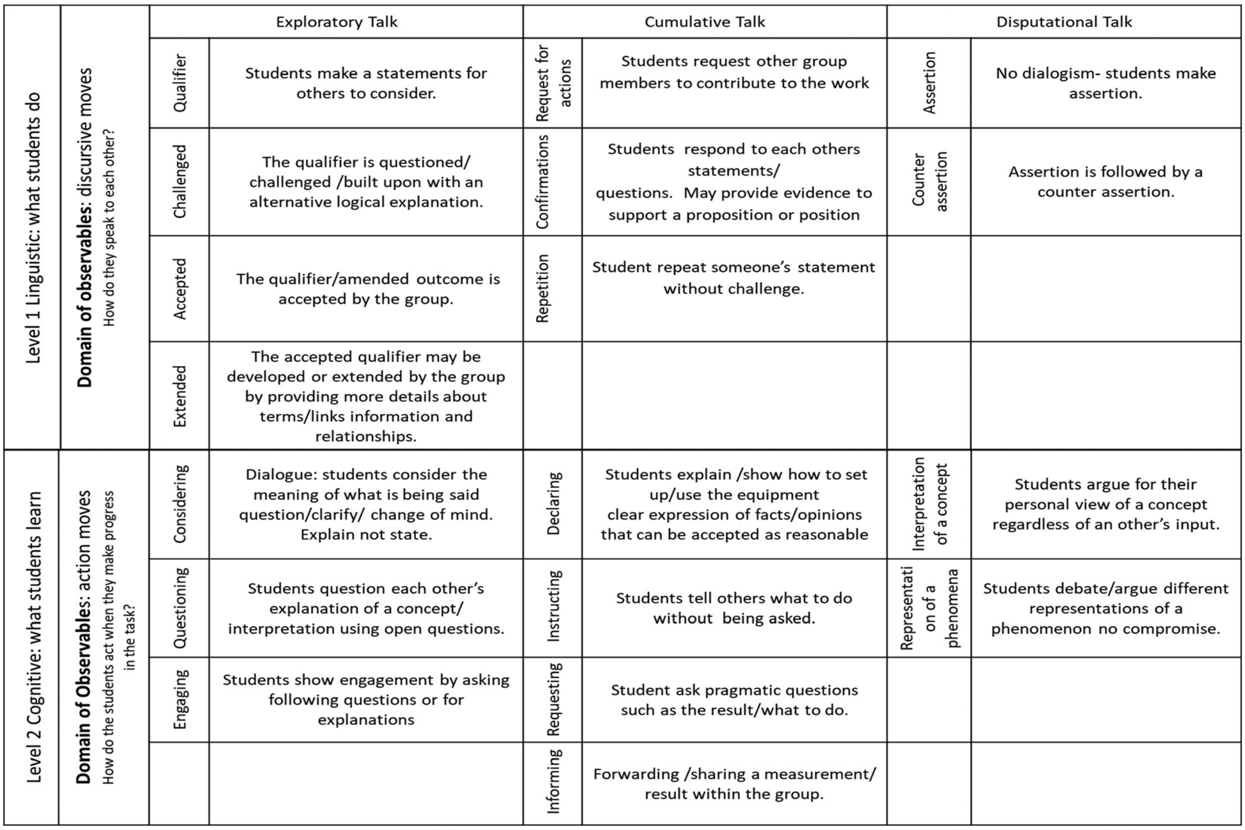
Conflicts of interest

There are no conflicts to declare.

Appedix

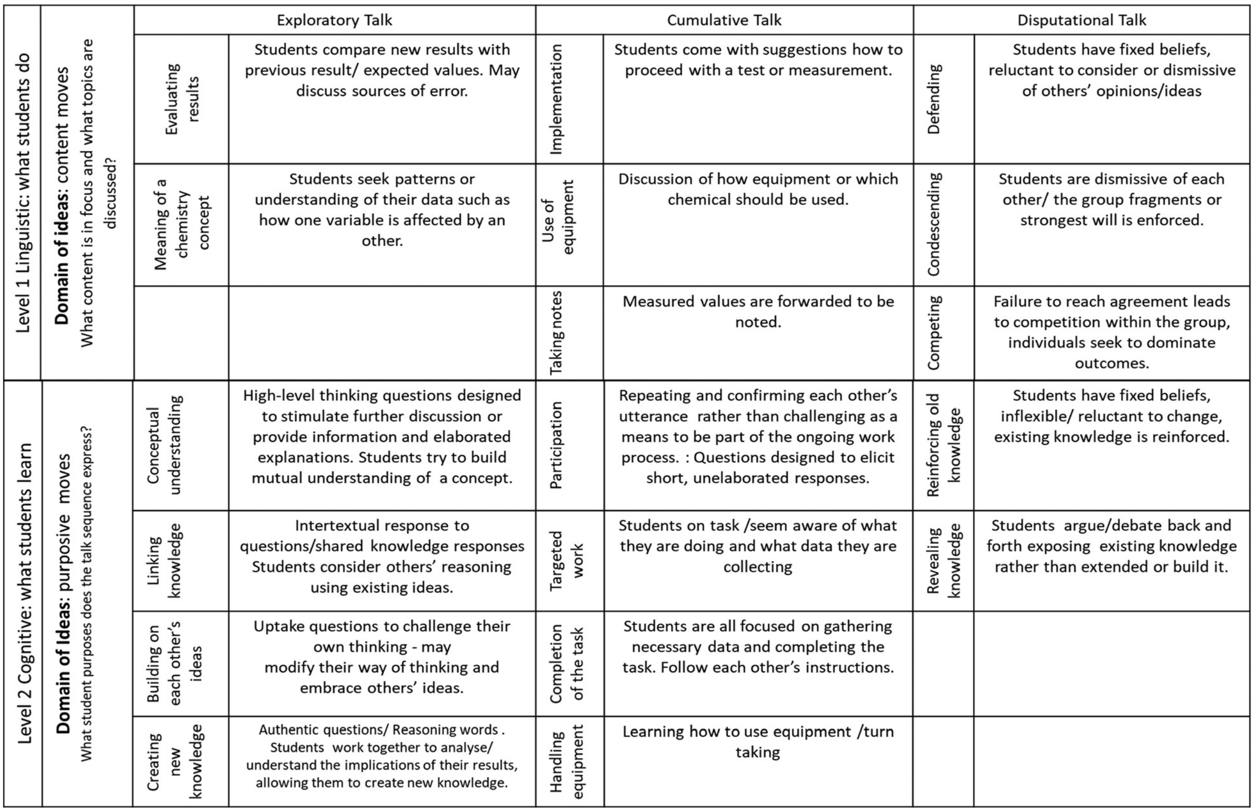
Appendix 1: The Talk ID Grid identifies and describes ta-lk moves used to code student talk

The Talk ID Grid to for the Domain of observables.



		Exploratory Talk		Cumulative Talk		Disputational Talk	
Level 1 Linguistic: what students do	**Domain of observables**: discursive moves How do they speak to each other?	Qualifier	Students make a statements for others to consider.	Request for actions	Students request other group members to contribute to the work	Assertion	No dialogism- students make assertion.
		Challenged	The qualifier is questioned/ challenged /built upon with an alternative logical explanation.	Confirmations	Students respond to each others statements/ questions. May provide evidence to support a proposition or position	Counter assertion	Assertion is followed by a counter assertion.
		Accepted	The qualifier/amended outcome is accepted by the group.	Repetition	Student repeat someone's statement without challenge.		
		Extended	The accepted qualifier may be developed or extended by the group by providing more details about terms/links information and relationships.				
Level 2 Cognitive: what students learn	**Domain of Observables**: action moves How do the students act when they make progress in the task?	Considering	Dialogue: students consider the meaning of what is being said question/clarify/ change of mind. Explain not state.	Declaring	Students explain /show how to set up/use the equipment clear expression of facts/opinions that can be accepted as reasonable	Interpretation of a concept	Students argue for their personal view of a concept regardless of an other's input.
		Questioning	Students question each other's explanation of a concept/ interpretation using open questions.	Instructing	Students tell others what to do without being asked.	Representati on of a phenomena	Students debate/argue different representations of a phenomenon no compromise.
		Engaging	Students show engagement by asking following questions or for explanations	Requesting	Student ask pragmatic questions such as the result/what to do.		
				Informing	Forwarding /sharing a measurement/ result within the group.		

The Talk ID Grid to for the domain of ideas.



		Exploratory Talk		Cumulative Talk		Disputational Talk	
Level 1 Linguistic: what students do	**Domain of ideas**: content moves What content is in focus and what topics are discussed?	Evaluating results	Students compare new results with previous result/ expected values. May discuss sources of error.	Implementation	Students come with suggestions how to proceed with a test or measurement.	Defending	Students have fixed beliefs, reluctant to consider or dismissive of others' opinions/ideas
		Meaning of a chemistry concept	Students seek patterns or understanding of their data such as how one variable is affected by an other.	Use of equipment	Discussion of how equipment or which chemical should be used.	Condescending	Students are dismissive of each other/ the group fragments or strongest will is enforced.
				Taking notes	Measured values are forwarded to be noted.	Competing	Failure to reach agreement leads to competition within the group, individuals seek to dominate outcomes.
Level 2 Cognitive: what students learn	**Domain of Ideas**: purposive moves What student purposes does the talk sequence express?	Conceptual understanding	High-level thinking questions designed to stimulate further discussion or provide information and elaborated explanations. Students try to build mutual understanding of a concept.	Participation	Repeating and confirming each other's utterance rather than challenging as a means to be part of the ongoing work process. : Questions designed to elicit short, unelaborated responses.	Reinforcing old knowledge	Students have fixed beliefs, inflexible/ reluctant to change, existing knowledge is reinforced.
		Linking knowledge	Intertextual response to questions/shared knowledge responses Students consider others' reasoning using existing ideas.	Targeted work	Students on task /seem aware of what they are doing and what data they are collecting	Revealing knowledge	Students argue/debate back and forth exposing existing knowledge rather than extended or build it.
		Building on each other's ideas	Uptake questions to challenge their own thinking - may modify their way of thinking and embrace others' ideas.	Completion of the task	Students are all focused on gathering necessary data and completing the task. Follow each other's instructions.		
		Creating new knowledge	Authentic questions/ Reasoning words . Students work together to analyse/ understand the implications of their results, allowing them to create new knowledge.	Handling equipment	Learning how to use equipment /turn taking		

Appendix 2: learning objectives and practical task methods

Litmus lesson Learning Objective: Categorise substances as acid, alkali, or neutral using experimental observations.

Litmus task method

1. Tear each piece of litmus paper into three smaller pieces.
2. Place a small piece of red litmus paper into one well of the spotting tile.
3. Using a pipette, add a drop of sulphuric acid to the red litmus paper.
4. Record your observation in the results table (shown below).
5. Repeat steps 1 to 4 with a small piece of blue litmus paper.
6. Using the two litmus paper results complete the analysis column of the table.
7. Repeat steps 1 to 6 with the remaining five solutions.
8. Dispose of the pieces of litmus paper in the waste bin.

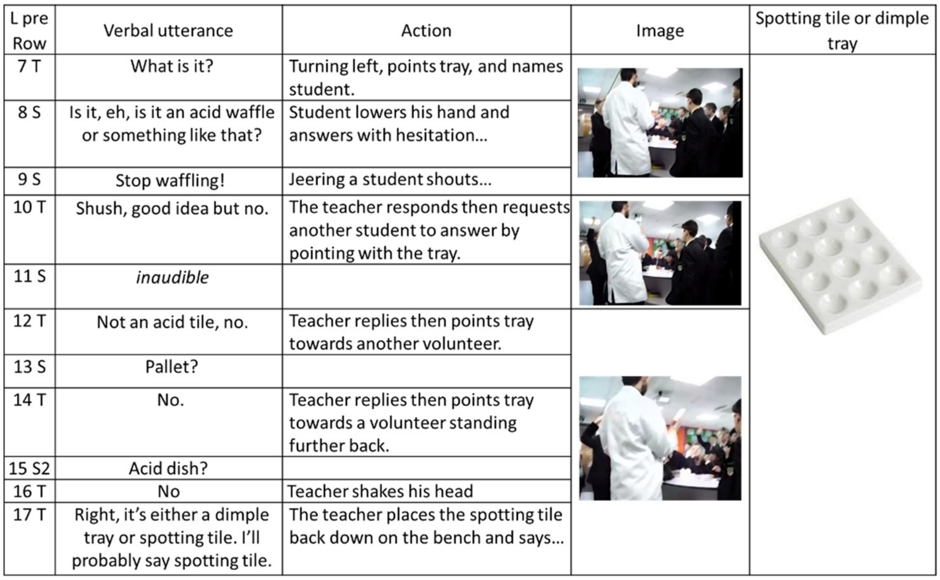
Neutralisation lesson Learning Objective: Describe how pH changes in neutralisation reactions and relate these changes to the colour of universal indicator.

Neutralisation task method

1. Pour 10 cm^3 hydrochloric acid into a conical flask.
2. Add a few drops of universal indicator and swirl the beaker carefully.
3. Pour 9 cm^3 sodium hydroxide solution into a second beaker.
4. Using a pipette, carefully add the sodium hydroxide drop by drop to the conical flask containing acid and universal indicator. Keep swirling.
5. As the sodium hydroxide is added note the colour changes and the number of drops added to produce the change.

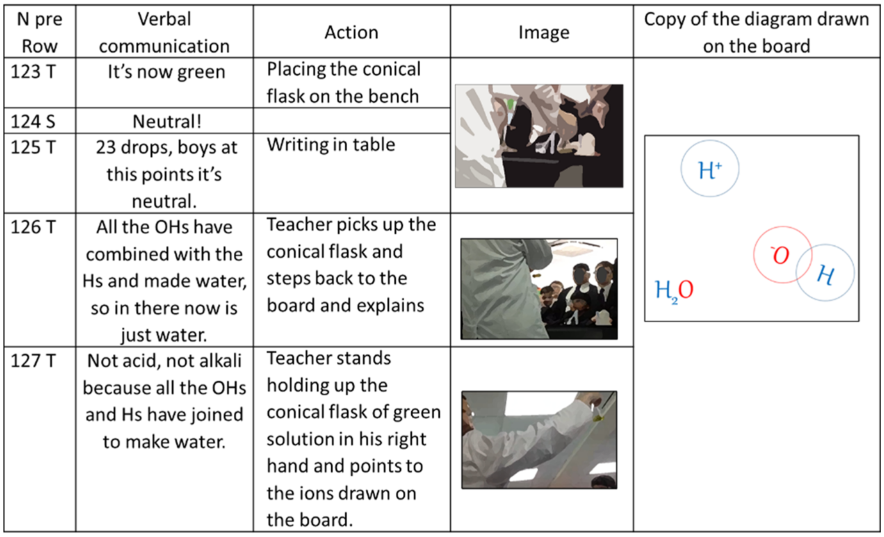
Appendix 3: Exemplar extracts of multimodal communication data from the practical lessons

Extract 1: Litmus lesson pre-experimental phase IRF sequence



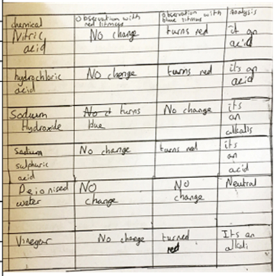
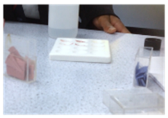
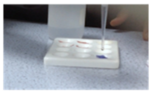
L pre Row	Verbal utterance	Action	Image	Spotting tile or dimple tray
7 T	What is it?	Turning left, points tray, and names student.		
8 S	Is it, eh, is it an acid waffle or something like that?	Student lowers his hand and answers with hesitation…		
9 S	Stop waffling!	Jeering a student shouts…		
10 T	Shush, good idea but no.	The teacher responds then requests another student to answer by pointing with the tray.		
11 S	*inaudible*			
12 T	Not an acid tile, no.	Teacher replies then points tray towards another volunteer.		
13 S	Pallet?			
14 T	No.	Teacher replies then points tray towards a volunteer standing further back.		
15 S2	Acid dish?			
16 T	No	Teacher shakes his head		
17 T	Right, it's either a dimple tray or spotting tile. I'll probably say spotting tile.	The teacher places the spotting tile back down on the bench and says…		

Extract 2: Neutralisation lesson pre-experimental phase, teacher monologue



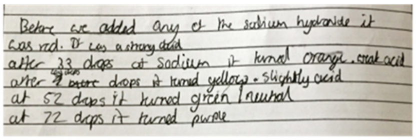
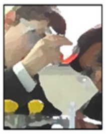
N pre Row	Verbal communication	Action	Image	Copy of the diagram drawn on the board
123 T	It's now green	Placing the conical flask on the bench		
124 S	Neutral!			
125 T	23 drops, boys at this points it's neutral.	Writing in table		
126 T	All the OHs have combined with the Hs and made water, so in there now is just water.	Teacher picks up the conical flask and steps back to the board and explains		
127 T	Not acid, not alkali because all the OHs and Hs have joined to make water.	Teacher stands holding up the conical flask of green solution in his right hand and points to the ions drawn on the board.		

Extract 3: Litmus lesson experimental phase, Group 1 exploratory talk

LG1 Row	Verbal communication	Action	Image	Written
128 S3	Have we done this?	Holding up a bottle of deionised water asks…		
129 S2 and S1	No	Both reply together…		
130 S3	So we're doing that then.	Unscrewing the lid.		
131 S2	Yeah	Continues ruling a line in his book and Sr1 nods		
132 S1	So I'm going to clean this for you.	S3 watches S1 take the pipette and says		
133 S3	Ok, go clean it, thanks.	S1 walks off to the sink and S3 looks at the spotting tray		
134 S2	You've got to get the bit of paper out.	Turning to S3 says…		
135 S3	Red or blue	S3 asks…		
136 S2	Litmus, red then blue.	S2 responds emphasising the word litmus. S3 puts a piece of red litmus in a well followed by blue litmus.		
137 S1	What is this called?	S1 returns and starts to write in his book, turning to S2 who is holding the next sample bottle asks…		
138 S2	Deionised water.	Whilst writing the name in his own table responds…		
139 S1	De-ion-ised water	S1 sounds out the name as he writes.		
140 S3	So the pink one?	Looking at red litmus in the dimple tray in front of S2 asks…		
141 S2	It's called red litmus paper not pink.	Corrects S3.		
142 S3	Ready guys?	Holding the filled pipette over the dimple tray well asks…		
143 S1	Ok go.	All three boys watch as S3 releases a drop onto the red litmus paper.		
144 S3	Nothing happened, it's the same.	Sounding disappointed says…		
145 S1	No change, it is not an alkali.	S1 nods and rephrases the observation as modelled by the teacher		
146 S2	Blue one?	S2 looks up from writing in his table.		
147 S2	Have you done the blue one yet?	S3 looks at him so S2 clarifies.		
148 S3	No not yet.	Responds…		
149 S3	Its going to change	Holding the pipette of deionised water above the blue litmus predicts…		
150 S1 and S2	No it's not, no change	The other members of the group reply talking at the same time just as the drop hits the blue litmus paper…		
151 S1	It's not an acid so had to be neutral	S1 speaks as he and S2 write the result in their books.		
152 S3	So if they both don't change then its neutral?	S3 has a puzzled expression as he speaks.		
153 S1	That's right.	S2 nods but S1 confirms.		
154 S3	Ok it's water, that makes sense	S3's expression changes from confused into understanding. He lifts his hand and taps his head to show understanding.		
155 S3	Is that it the we're done?	He looks down at S1's book and asks…		
156 S3	Wait did any of the reds turn blue?	Looking at the results he says…		
157 S1	Yeah, look sodium hydroxide	Pointing at his table.		

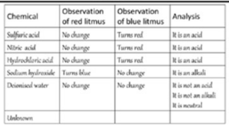
chemical	Observation with red litmus	Observation with blue litmus	Analysis
Nitric acid	No change	turns red	it an acid
hydrochloric acid	No change	turns red	it's an acid
Sodium Hydroxide	~~No it~~ turns blue	No change	its an alkalis
Sodium sulphuric acid	No change	turns red	its an acid
Deionised water	NO change	NO change	Neutral
Vinegar	No change	turned red	Its an alkali

Extract 4: Neutralisation lesson experimental phase, Group 2 Cumulative Talk

NG2 Row	Verbal communication	Action	Image	Written
91 SK	Hey is that orange	Adding drops with the pipette		
92 SL	Yes it's orange	Swirling the flask		
93 SL	We're on 20	Checks SL		
94 SK	30	Corrects SK		
95 SL	Oh yeah, write 30 turned orange	Confirms		
96 SL	Put it back in.	SK turns to write still holding the pipette SL Grabbing pipette demands (into the sodium hydroxide solution)		
97 SK	It's still red.	Looking at the conical flask SL has set down on the bench		
98 SK	Still red	SL looks down and SK repeats		
99 SL	Fine	SL begins squirting in the sodium hydroxide and arbitrarily stating numbers.		
100 SL	31,32,33	SL is not mixing so SK picks up the conical flask and gives it a swirl		
101 SL	Spin, spin	Grabbing the flask off SK in a "mad scientist voice" says		
102 SL	Oh you've no idea how to spin a scientific conical flask.	Theatrically demonstrating swirling the flask		
103 SL	Now that's orange	Triumphantly holding the conical flask aloft		
104 SK	Its orange	Nodding in agreement picks up his pen		
105 SL	23	Repeats the number of drops of sodium hydroxide added		
106 SK	33	Corrects SL and amends his written results.		

Before we added any of the sodium hydroxide it was red. It was a strong acid
after 33 drops of Sodium it turned orange. weak acid
after [illegible] more drops it turned yellow. slightly acid
at 52 drops it turned green / neutral
at 72 drops it turned purple

Extract 5: Litmus lesson post-experimental phase IRF sequence

<table>
<tr><th>L post Row</th><th>Verbal communication</th><th>Activity</th><th>Image</th><th>Copy of the table drawn on the board</th></tr>
<tr><td>92 SK</td><td>In red litmus no change.</td><td>The teacher nods to a student who begins to respond…</td><td rowspan="3"></td><td rowspan="3">
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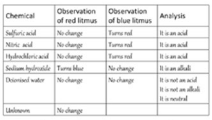
<tr><th>Chemical</th><th>Observation of red litmus</th><th>Observation of blue litmus</th><th>Analysis</th></tr>
<tr><td>Sulfuric acid</td><td>No change</td><td>Turns red</td><td>It is an acid</td></tr>
<tr><td>Nitric acid</td><td>No change</td><td>Turns red</td><td>It is an acid</td></tr>
<tr><td>Hydrochloric acid</td><td>No change</td><td>Turns red</td><td>It is an acid</td></tr>
<tr><td>Sodium hydroxide</td><td>Turns blue</td><td>No change</td><td>It is an alkali</td></tr>
<tr><td>Deionised water</td><td>No change</td><td>No change</td><td>It is not an acid
It is not an alkali
It is neutral</td></tr>
<tr><td>Unknown</td><td></td><td></td><td></td></tr>
</table></td></tr>
<tr><td>93 T</td><td>So what does that tell us?</td><td>Nodding the teacher asks…</td></tr>
<tr><td>94 SK</td><td>That there wasn't, that its not an ac, alkali.</td><td>The student responds promptly, self correcting as he does so.</td></tr>
<tr><td>95 T</td><td>Good it wasn't an alkali.</td><td>Smiling and pointing his pen at the student the teacher confirms the student was correct then starts to write the results on the board.</td><td></td><td>
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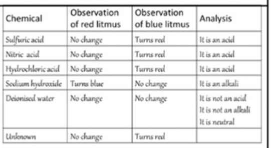
It is not an alkali
It is neutral</td></tr>
<tr><td>Unknown</td><td>No change</td><td></td><td></td></tr>
</table></td></tr>
<tr><td>96 SK</td><td>Observation with blue litmus it turned red so it was an acid.</td><td>The student continues unprompted…</td><td rowspan="2"></td><td rowspan="2">
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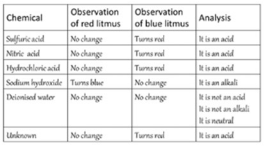
It is not an alkali
It is neutral</td></tr>
<tr><td>Unknown</td><td>No change</td><td>Turns red</td><td></td></tr>
</table></td></tr>
<tr><td>97 T</td><td>Good!</td><td>The teacher half turns away from the board to look at the student and confirms his response.</td></tr>
<tr><td>98 S</td><td>Surely it confirms it, because vinegar is an acid.</td><td>Another student interrupts by shouting out…</td><td rowspan="3"></td><td rowspan="3">
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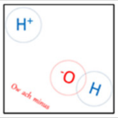
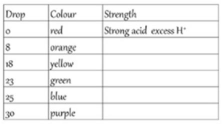
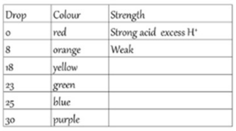
It is neutral</td></tr>
<tr><td>Unknown</td><td>No change</td><td>Turns red</td><td>It is an acid</td></tr>
</table></td></tr>
<tr><td>99 T</td><td>Yeah but we, there are millions of different acids, just because it is acidic it doesn't tell us its vinegar.</td><td>The teacher turns to respond to the student emphasising that this is an important point…</td></tr>
<tr><td>100 T</td><td>It's like a little bit of evidence in a court case.</td><td>The teacher qualifies this by using a familiar simile to help clarify the point…</td></tr>
</table>

Extract 6: Neutralisation lesson post-experimental phase IRF sequence

<table>
<tr><th>N post Row</th><th>Verbal communication</th><th>Action</th><th>Image</th><th>Copy of the diagram and table on the board</th></tr>
<tr><td>14 T</td><td>If we're weakly acidic what are we going to have more of?</td><td>The teacher swipes hand to indicated choice between H plus and OH minus.</td><td></td><td>
</td></tr>
<tr><td>15 S1</td><td>H plus.</td><td>The student responds tentatively…</td><td rowspan="2"></td><td rowspan="2">
<table>
<tr><th>Drop</th><th>Colour</th><th>Strength</th></tr>
<tr><td>0</td><td>red</td><td>Strong acid excess H^+</td></tr>
<tr><td>8</td><td>orange</td><td></td></tr>
<tr><td>18</td><td>yellow</td><td></td></tr>
<tr><td>23</td><td>green</td><td></td></tr>
<tr><td>25</td><td>blue</td><td></td></tr>
<tr><td>30</td><td>purple</td><td></td></tr>
</table></td></tr>
<tr><td>16 T</td><td>Yeah, we're still going to have more H plus aren't we.</td><td>Nodding the teacher confirms this answer…</td></tr>
<tr><td>17 T</td><td>I'm going to put extra H plus, just to mean that there is not as many as the excess H plus in the strong acid.</td><td>Turns back and begins writing on the board explaining as he does so…</td><td></td><td>
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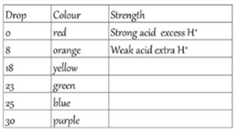
<tr><td>23</td><td>green</td><td></td></tr>
<tr><td>25</td><td>blue</td><td></td></tr>
<tr><td>30</td><td>purple</td><td></td></tr>
</table></td></tr>
<tr><td>18 T</td><td>Right what does the yellow one tell us?</td><td>The teacher finishes writing, steps back to make both boards fully visible and, points to student with hand up</td><td></td><td>
<table>
<tr><th>Drop</th><th>Colour</th><th>Strength</th></tr>
<tr><td>0</td><td>red</td><td>Strong acid excess H^+</td></tr>
<tr><td>8</td><td>orange</td><td>Weak acid extra H^+</td></tr>
<tr><td>18</td><td>yellow</td><td></td></tr>
<tr><td>23</td><td>green</td><td></td></tr>
<tr><td>25</td><td>blue</td><td></td></tr>
<tr><td>30</td><td>purple</td><td></td></tr>
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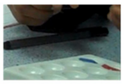
</table>

Appendix 4: An extract of cumulative talk deductively coded into Talk ID Grid

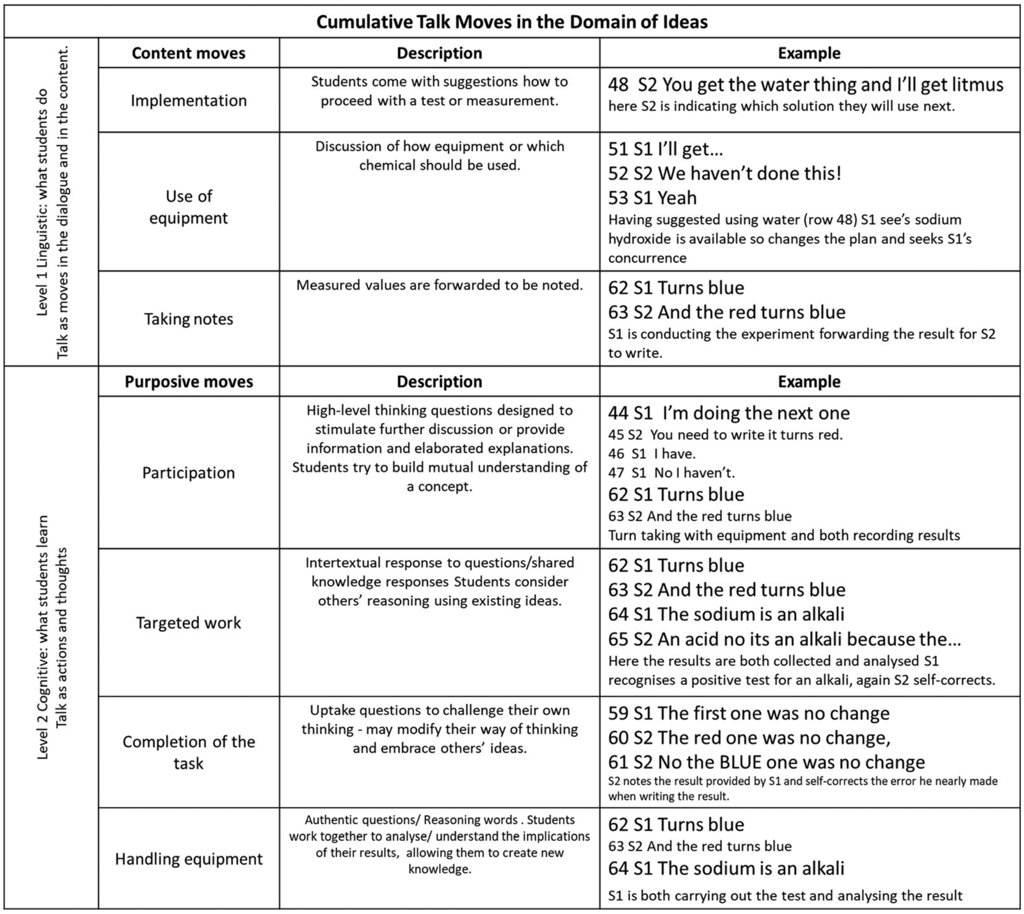
Extract 7: Experimental phase Litmus task Group 1 Cumulative Talk

Cumulative talk moves in the domain of observables in which: discursive moves characterise the manner in which students work together; and action moves which describe how students engage with each other's ideas.

Cumulative talk moves in the domain of ideas in which: content moves characterise students' analysis of data; and purpose moves which describe how the students think together to understand their data.

LG1 Row	Verbal communication	Action	Image
42 S2	We need more litmus		
43 S2	It's stuck to it	Trying to push the used litmus further into the well to clear a space for the next test .	
44 S1	I'm doing the next one	S2 nods.	
45 S2	You need to write it turns red	Looking in S1's book…	
46 S1	I have	Turns and looks in his book	
47 S1	No I haven't.	Laughs…	
48 S2	You get the water thing and I'll get litmus	S2 reaches down the bench takes blue litmus and places it in the well then picks up a bottle of solution S1 looks up from his book and nods.	
49 S2	Have we done sodium hy…	S2 sees a bottle of sodium hydroxide and reaches along the bench for it asking…	
50 S2	no	Looking in his book answers his own question…	
51 S1	I'll get…	S1 seems not to have realised that S2 has changed the plan and now wants to use the solution that is in front of him.	
52 S2	We haven't done this!	S2 still holding the bottle	
53 S1	Yeah	S2 puts the bottle down on the bench in front of S1. S1 agrees	
54 S2	Stop	S student from a different group reaches over to take sodium hydroxide bottle.	
55 S2	Stop we're using that	S1 reaches over and grabs the bottle (Agreement)	
56 S1	Is this sodium hydroxide?	Holding the reagent bottle, asks before turning the bottle and reading the label.	
57 S2	We haven't done that yet.	S2 replies in what sounds likes an apologetic tone whilst writing sodium hydroxide in the table of his book.	
58 S1	We haven't done sodium hydroxide.	S1 adds a drop of sodium hydroxide to blue litmus paper	
59 S1	The first one was no change	Looking at the well containing the litmus tells S2 reports…	
60 S2	The red one was no change,	Drawing a line in his book speaks then looks at the spotting tile.	
61 S2	No the BLUE one was no change.	Then corrects himself…	
62 S1	Turns blue	Meanwhile, S1 adds the sodium hydroxide to the red litmus and states…	
63 S2	And the red turns blue	Repeating S1 as he writes.	
64 S1	The sodium is an alkali	S1 writes his analysis stating…	
65 S2	An acid. No it's an alkali because the…	S2 begins to contradict S1 but corrects himself before being interrupted by the arrival of S3	

Cumulative Talk Moves in the Domain of Observables			
Level 1 Linguistic: what students do Talk as moves in the dialogue and in the content.	**Discursive moves**	**Description**	**Example**
	Request for actions	Students request other group members to contribute to the work	48 S2 You get the water thing and I'll get litmus
	Confirmations	Students respond to each others statements/ questions. May provide evidence to support a proposition or position	44 S1 I'm doing the next one 45 S2 You need to write it turns red. 46 S1 I have. 47 S1 No I haven't. S1 responds to S2's direction.
	Repetition	Student repeat someone's statement without challenge.	49 S2 Have we done sodium hy… 58 S1 We haven't done sodium hydroxide. S1 and S2 are talking in parallel failing to engage with each other's comments
Level 2 Cognitive: what students learn Talk as actions and thoughts	**Action moves**	**Description**	**Example**
	Declaring	Students explain /show how to set up/use the equipment clear expression of facts/opinions that can be accepted as reasonable	42 S2 We need more litmus looks at the equipment and identifies what is needed to proceed.
	Instructing	Students tell others what to do without being asked.	45 S2 You need to write it turns red.
	Requesting	Student ask pragmatic questions such as the result/what to do.	56 S1 Is this sodium hydroxide? Seeking confirmation that he's about to use the correct chemical.
	Informing	Forwarding /sharing a measurement/ result within the group.	59 S1 The first one was no change informs S2 who is writing in his table



Cumulative Talk Moves in the Domain of Ideas

Level 1 Linguistic: what students do Talk as moves in the dialogue and in the content.	**Content moves**	**Description**	**Example**
	Implementation	Students come with suggestions how to proceed with a test or measurement.	48 S2 You get the water thing and I'll get litmus here S2 is indicating which solution they will use next.
	Use of equipment	Discussion of how equipment or which chemical should be used.	51 S1 I'll get… 52 S2 We haven't done this! 53 S1 Yeah Having suggested using water (row 48) S1 see's sodium hydroxide is available so changes the plan and seeks S1's concurrence
	Taking notes	Measured values are forwarded to be noted.	62 S1 Turns blue 63 S2 And the red turns blue S1 is conducting the experiment forwarding the result for S2 to write.
Level 2 Cognitive: what students learn Talk as actions and thoughts	**Purposive moves**	**Description**	**Example**
	Participation	High-level thinking questions designed to stimulate further discussion or provide information and elaborated explanations. Students try to build mutual understanding of a concept.	44 S1 I'm doing the next one 45 S2 You need to write it turns red. 46 S1 I have. 47 S1 No I haven't. 62 S1 Turns blue 63 S2 And the red turns blue Turn taking with equipment and both recording results
	Targeted work	Intertextual response to questions/shared knowledge responses Students consider others' reasoning using existing ideas.	62 S1 Turns blue 63 S2 And the red turns blue 64 S1 The sodium is an alkali 65 S2 An acid no its an alkali because the… Here the results are both collected and analysed S1 recognises a positive test for an alkali, again S2 self-corrects.
	Completion of the task	Uptake questions to challenge their own thinking - may modify their way of thinking and embrace others' ideas.	59 S1 The first one was no change 60 S2 The red one was no change, 61 S2 No the BLUE one was no change S2 notes the result provided by S1 and self-corrects the error he nearly made when writing the result.
	Handling equipment	Authentic questions/ Reasoning words . Students work together to analyse/ understand the implications of their results, allowing them to create new knowledge.	62 S1 Turns blue 63 S2 And the red turns blue 64 S1 The sodium is an alkali S1 is both carrying out the test and analysing the result

Appendix 5: The extract of disputational talk deductively coded into Talk ID Grid

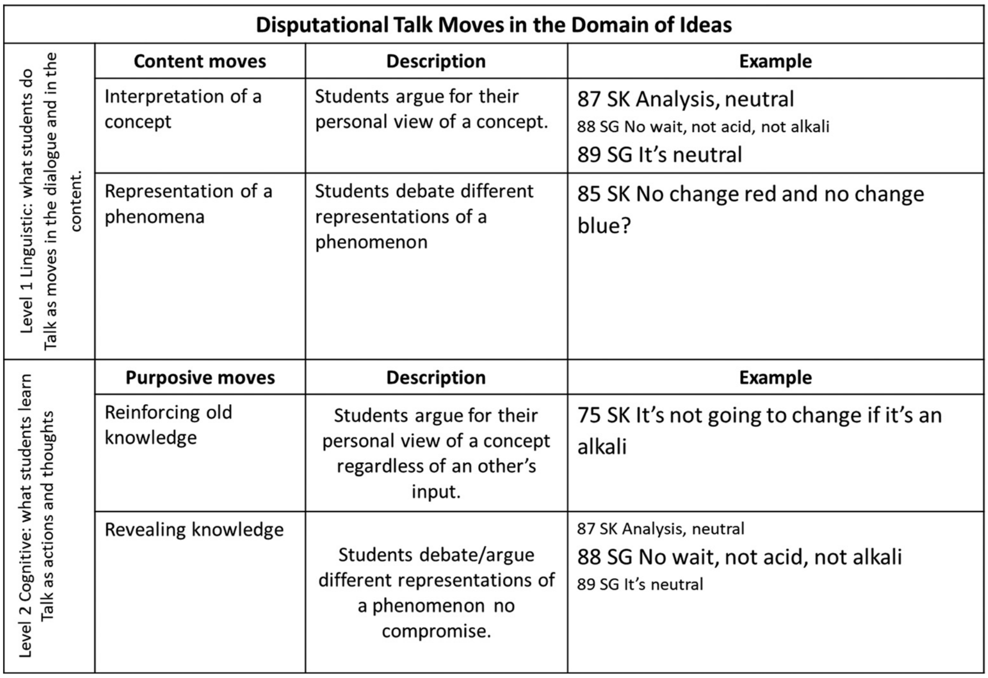
Extract 8: Experimental phase Litmus Task Group 2 Disputational Talk

Disputational talk moves in the domain of observables in which: discursive moves characterise the manner in which students work together; and action moves which describe how students engage with each other's ideas.

Disputational talk moves in the domain of ideas in which: content moves characterise students' analysis of data; and purpose moves which describe how the students think together to understand their data.

LGp2 Row	Verbal communication	Action	Image
60 SL	Acid Turf Wars	Leaning right over the dropping tile, obscuring it from the rest of the group	
61 SL	Acid Turf Wars 101	Providing a personal commentary on the activity	
62 SL	I'll get more blue	SL walks off without waiting for a response	
63 SG	He really annoys me	SG turns and quietly speaks to SK about SL. SK nods in agreement. SL returns brandishing the litmus paper	
64 SL	I have blue paper	SL rips the blue litmus paper and puts it in the tray next to the well with the red litmus paper he set up earlier. He then takes the bottle of deionised water and the pipette without looking nor talking to the other members of his group.	
65 SK	Wait.	SK checks the blue litmus	
66 SK	Ok yeah	Nods	
67 SL	Observation one	SL fills the pipette right up	
68 SG	That's a lot	SG regards SL and the pipette critically	
69 SK	You hardly need any	SK supporting SG's criticism adding…	
70 Sg	Squeeze a bit out	Commands	
71 SG	Ok that's enough	Very little of the deionised water has been removed from the pipette but nevertheless SG seems satisfied	
72 SL	Ok	Drops deionised water on the blue litmus	
73 SG	Ok enough,	Holding his hand palm out indicating that SL must not add more	
74 SG	That's enough	Demands	
75 SK	It's not going to change if it's an alkali	Moves towards the blue litmus	
76 SL	Right, red	SL prepares to add the solution to the red litmus	
77 SG	No!	Again SG holds his hand out indicating SL must mot test the red litmus yet	
78 SG	Need to write it down	SG qualifies the command, and SL stops but continues to clutch the solution and pipette makes no attempt to write down the results	
79 SK	Write it down afterwards	SK suggests to SG, so SL moves to continue with the test	
80 SG	Stop!	Raising his voice SG demands that SL does not continue. SG is controlling the situation and rigidly sticking to the procedure demonstrated by the teacher /dictated by the results table	
81 SG	Write it down first	SK concurs and turns to his book to write but SL skill clutches the equipment protectively. and continues although the rest of the group is writing	
82 SL	So red no change.	SK and SG look up from their books towards the spotting tile	
83 SG	What you've already done it?	SG sounding cross demands	
84 SG	When we weren't looking?	SG sounds really cross but SL does not react.	
85 SK	No change red and no change blue?	Clarifying the results to record in his table.	
86 SL	Turf wars 101 decider	Holding another bottle of chemicals and ignoring the rest of the group.	
87 SK	Analysis, neutral	Talking as he writes	
88 SG	No wait, not acid, not alkali	Reading out his results	
89 SG	It's neutral	Stating his own analysis.	

Disputational Talk Moves in the Domain of Observables			
Level 1 Linguistic: what students do Talk as moves in the dialogue and in the content.	**Discursive moves**	**Description**	**Example**
	Assertion	No dialogism- students make assertion.	77 SG No! 78 SG Need to write it down.
	Counter assertion	Assertion is followed by a counter assertion.	79 SK Write it down afterwards
Level 2 Cognitive: what students learn Talk as actions and thoughts	**Action moves**	**Description**	**Example**
	Defending	Students argue for their personal view of a concept regardless of an other's input.	Ignoring both SG and SK, SL continues with the test 82 SL so red no change
	Condescending	Students debate/argue different representations of a phenomenon no compromise.	83 SG What you've already done it? 84 SG When we weren't looking?
	Competing	Students argue for their personal view of a concept regardless of an other's input.	68 SG That's a lot SG regards SL and the pipette critically 69 SK You hardly need any SK supporting SG's criticism adding… 70 SG Squeeze a bit out Commands



Disputational Talk Moves in the Domain of Ideas

	Content moves	Description	Example
Level 1 Linguistic: what students do Talk as moves in the dialogue and in the content.	Interpretation of a concept	Students argue for their personal view of a concept.	87 SK Analysis, neutral 88 SG No wait, not acid, not alkali 89 SG It's neutral
	Representation of a phenomena	Students debate different representations of a phenomenon	85 SK No change red and no change blue?
Level 2 Cognitive: what students learn Talk as actions and thoughts	**Purposive moves**	**Description**	**Example**
	Reinforcing old knowledge	Students argue for their personal view of a concept regardless of an other's input.	75 SK It's not going to change if it's an alkali
	Revealing knowledge	Students debate/argue different representations of a phenomenon no compromise.	87 SK Analysis, neutral 88 SG No wait, not acid, not alkali 89 SG It's neutral

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Chapter 5 Meta-learning

What impact has practice-oriented research had on my understanding of school chemistry education?

A new, more challenging, National Curriculum was introduced in 2014 (UK Government 2015 b), reportedly to counter the UK's disappointing rank in the global league tables (Meyer & Benavot 2013). However, global benchmarking may be thought to be fundamentally flawed as global statistics implicitly assume a world culture theory, and isomorphism of the outcomes of school curricula across the globe (Ramirez 2012).

The neo-liberal education policy employs statistical and forecast tools of governance 'datafication' and 'big data' modes of analysis. Performance measures are used to judge a student's progress for which the teacher, and the school are held accountable. Value-added as an example, uses a student's academic performance compared to their performance at an earlier stage to present a measure of educational progress. This is problematic as the model assumes a linear growth in student performance between 11 and 16 years and that fluctuations in attainment due to extenuating or exceptional circumstances will be accommodated by the large sample size. Although I recognised the flaws in using forecasts and statistics to benchmark education, my concerns about the curriculum reforms focussed on my students and my teaching.

The 2013 survey into science education in schools began by stating that the most successful schools visited, and the best science teachers observed had adopted a "first maintain curiosity" principle to foster enthusiasm for science and to help learners fulfil their potential. (Ofsted. 2013 p. 4). Ofsted recognised that too many school leavers lacked the practical, investigative, and analytical skills needed to contribute to the Nation's economic development. The anticipated curriculum reforms provided "a timely opportunity to ensure that the skills of scientific enquiry are assessed as an integral part of these qualifications" (Ofsted. 2013 p. 4).

The reformed science curriculum that followed, requires students to build substantive knowledge (models and theories etc.) and disciplinary knowledge (the practices of science known as working scientifically) both of which are underpinned by knowledge of concepts and procedures (Ofsted 2021). However, practical work is not directly assessed, and the exam specification does not include "be able to" when describing apparatus and techniques, I interpreted this as the imperative for class practical work had been removed. Science education seemed to be moving towards the banking concept of education, in which knowledge is deposited in students by the teacher (Freire, & Ramos, 2009). In the banking model a teacher's job is to fill students with "contents which are detached from reality, disconnected from the totality that engendered them and could give them significance" (p. 163). I felt that I now needed to be able to justify retaining practical work in much of my teaching.

Sociocultural theory and socio-material theory are combined within CHAT to provide a methodological framework for studying practice-based learning in complex learning environments (Qureshi 2021). Through the application of the CHAT activity system, learning can be understood to occur through practice, collective activity, and is mediated by culturally specific instruments (Figure 3.3). So, the activity of carrying out practical work contextualises chemistry concepts and allows students to work together to construct knowledge.

Transformative approaches to teaching begin with trying something different which will offer a new lens (Murphy *et al*., 2015). Responding to Michael Seery's call for partners to trial his digital badge protocol[9] triggered the chain of events that led to finding this lens, CHAT. Contradictions within the CHAT activity system result in an activity not leading to its desired outcome, and that change or development result from conflict resolution (Foot 2014). The work described in this thesis details how I have sought to resolve the conflict caused by the contradiction between the requirements of practical assessment, and the demands of "first maintain curiosity", and purposeful practical work. Practice-oriented research is the agency by which I have transformed my teaching and has developed my academic voice.

So, what was the impact of practice-oriented research on my ontology and epistemology?

At the onset of this work, I perceived a single objective reality, and that knowledge can be obtained using reliable and valid measurement tools, and so I sought to measure learning and use statistics to generate facts. However, through reflexivity I began to interrogate these assumptions and drew on my teaching experience to do so. Figure 2.1 presented a summary of the development of my theoretical thinking.

My first realisation was the subjective nature of reality as demonstrated by physicists using a set of coordinates, a frame of reference, to determine positions and velocities of objects. For example, if I throw a ball when I'm on a train moving at constant velocity, I will see the ball travel straight up and down. Whereas, if you are standing on a stationary platform, the ball will be seen to move in a

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[9] https://badginglabskills.wordpress.com/2016/08/23/getting-ready-to-badge-and-looking-for-interested-partners/

parabola. The ball is the same but the path it travels differs depending on the observer's frame of reference because the frames of reference move relative to one another. Accepting that human experiences of the ball vary but the ball itself does not, is to understand that the world as it appears to us is different from the world as it is independent of us. This understanding is described as structural realism, and it posits that science describes reality, but its true nature remains uncertain.

I then assumed that if more than one approach to data collection was adopted and that analyses of the resultant data supported each other, the certainty of conclusions drawn would be increased. It was with this understanding that I adopted the mixed method approaches and quasi-experimental design described in Paper 2, Chapter 2, and Paper 3, Chapter 3. I realised that the value I attributed to qualitative data changed because I now recognised the subjective nature of human experience.

Returning to the previous analogy, when the ball is seen, its pathway is a property of the observer's visual experience. To gain knowledge of this experience demands communication, and it is only through communication that a shared understanding or knowledge, of the observers' visual experience can be constructed. If a shared understanding is built through communication, then the communication event provides a point of access to the understanding that is built.

The effects of understanding that knowledge construction, learning, could be accessed through studying communication was two-fold. Firstly, I adopted the methodology, described in Paper 4, Chapter 4, in which multimodal communication was analysed to understand learning through practical work. And secondly, I was able to expound my objection to the banking model of education; knowledge is not a commodity that can be transferred instead, knowledge is built and refined by communicative events.

My greatest revelation from undertaking practice-oriented research was understanding that reality is described by science, rather than exposed by science. A description is a linguistic account, not subjective truth, this comprehension transforms the nature of concepts. I now understand that chemical concepts do not exist in the abstract but "can be described as systematic mental representations of the natural world," Kampourakis (2018, p. 591). However, if mental constructs are to be shared then communication is critical. 'Language does not merely describe or reflect pre-existing conceptual structures; language actively creates those structures.' Keys (1999, p. 115).

Spoken language and multimodal communication are the live counterparts of writing and drawing as mechanisms for expressing thought. Because they are the live counterparts, they afford an immediate response which makes them powerful classroom tools. Furthermore, multimodal communication can be understood to both express and form thought; "the text that comes from my mouth forms itself in speaking. There is no mental image of this text because I have not had the time to think about what I will be saying" (Roth 2012, p. 148-149), and gesture clarifies and supports speech (McNeill & Duncan 2023).

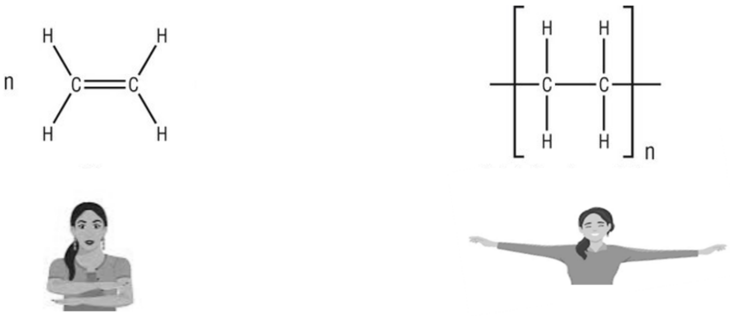
If the school chemistry curriculum details the substantive and disciplinary knowledge students must learn, then the question arises, what is knowledge? Knowledge is built and refined by communicative events; it is a phenomenon that emerges through dialogic interactions. Dialogic interactions are reciprocal exchanges in which information is explored and ideas are interrogated (Bakhtin 1981). In other words, telling does not generate knowledge, there must be an exchange so that what is told is shaped into a shared understanding. Knowledge may thus be conceived as a pattern of language use reconstructed and shared by members of a community.

Chemistry concepts are made and remade by the social use of language to share phenomena that can be perceived and studied. And so, learning chemistry is learning to use the language and meaning making conventions of the subject, and by attending to multimodal communication, we can ascertain the knowledge being constructed in that moment.

What now: comparing my laboratory pedagogy before and after undertaking practice-oriented research.

My teaching

I surmised that language and movement were connected, and I used gestures to help students recall specific concepts such as addition polymerisation, as shown in Figure 5.1. Using gesture seemed a small step away from manipulating equipment in the laboratory to support the recall of concepts. Through engaging with research, I have been able to rationalise this assumption, learning for example that language and gesture are intimately connected. Gesture can support memory and reduce the cognitive load imposed by a task (Cook & Fenn 2017) furthermore, gestures are components of speaking that can help articulation of thought (McNeill & Duncan 2023).



1. In addition polymerisation the monomer has a double bond.

2. Double bonds break open, and monomers join to make a polymer

Figure 5.1, using arm movements to help students to understand and remember addition polymerisation in GCSE chemistry.

Practice-oriented research has been reported to have a positive impact on student learning (Baumfield & Butterworth 2005), and research-engaged teachers have ‘a better understanding of their practice and ways to improve it’ (McLaughlin *et al*., 2004, p. 5). My research has focussed on developing oracy in the school chemistry laboratory to enhance students’ learning and in the following section I will describe how this work has impacted on my teaching.

When planning and delivering my lessons, I draw on the knowledge and understanding built through research, this is evident when comparing lesson plans. In Figure 5.2, two lesson plans for the GCSE electrolysis practical, which was discussed in Paper 3, Chapter 3, demonstrate the impact of research on my teaching.

A GCSE required practical lesson would now ask students to watch an exemplar video as pre-laboratory preparation to build familiarity with equipment and procedures and reduce the cognitive load that novelty imposes. In the lesson, students work in habitual groups of three to establish a group identity.

Plan	2016	2023
Homework		Ask students to watch the procedure video as a homework task
Practical lesson	Introduce the practical task and demonstrate electrolysis of the first solution (copper chloride)	1. Pre-experimental phase (introduce language) Teacher led class discussion with students to complete the electrolysis storyboard
	Students to set up and carryout practical task in groups of 3 and complete the table below	2. Experimental phase (use language) Students to set up and carryout practical task in groups of 3 and complete the table below
	Class discussion of results Exam style practical themed questions	3. Post-experimental phase (language reinforcement) Class discussion of results and inference. Can we build a generalisable conclusion? Exam style question (peer assessed from teacher feedback)
Homework	Complete exam style practical themed question	Ask students to watch the concept video as a homework task
Following lesson	Self- assessment of exam style practical themed question from teacher feedback	Exam style application question and retrieval practice (self-assessed from teacher feedback) Exam style Reflection: I am confident … I need to build my understanding of…

Figure 5.2, a plan of the GCSE electrolysis practical that now includes pre-laboratory preparation using the videos described in Paper 3, Chapter 3 and the three-part lesson structure and results table discussed in Paper 4, Chapter 4.

There follows a teacher-led whole-class discussion of the procedure including demonstrations of salient points, safety, and to ensure key terminology is identified and used. The students are given a blank copy of the results table, and as Figure 5.3 shows, the structure of the results table has been modified because of my research.

2016				
Solution	**Anode**		**Cathode**	
	observation	**element formed**	**observation**	**element formed**
Copper chloride	Bubbles litmus paper bleaches	chlorine	Pink metallic deposit	copper

2023										
Solution	**Prediction**		**Anode**			**Cathode**			**Inference**	
	anode	**cathode**	**observation**	**positive test**	**positive observation**	**observation**	**positive test**	**positive observation**	**anode**	**cathode**
Copper chloride	chlorine	copper	bubbles	Damp blue litmus paper	Turns red and bleaches	Pink metallic deposit	none	–	Chlorine gas	copper

Figure 5.3, how the structure of a results table has been modified to promote and support student discussion and draws on task analysis, as described in Chapter 1, to breakdown the procedure into separate techniques.

The practical activity is more tightly orchestrated to reserve time for discussion, for example, equipment will be collected and set up in an orderly manner and the students will be asked to stop and listen. Now that the equipment is in front of the students, I will ask them questions related to the table of results to emphasise what they need to talk about as well as do.
Finally, the class will be directed to stop and clear away in a structured manner before returning to their seats to discuss results and construct a general conclusion such as, if halide ions are not present then oxygen will be produced at the anode. I am conscious not to use chemical symbols at this stage, so only the macroscopic and submicroscopic levels of thought are in use, as a means of reducing the cognitive load imposed by the task.

The students will then work individually to answer a practical themed exam style question as both retrieval practice and to build familiarity with indirect practical assessment. Their written responses are swapped with a neighbour and exemplar answers are generated through teacher-led discussion. The students are expected to mark, correct, and improve work using green pen to capture verbal feedback.

In this example the students are then asked to watch the concept video before the following lesson. This lesson will then conclude the practical task by using a combination of exam-style questions that draw on the symbolic level of representation as this language was previously avoided. The students will also be given application questions to show how the knowledge from the task may be applied to a novel situation. An example of which would be sodium iodide in kelp and the production of iodine.

Detailed verbal feedback on these questions includes modelling how to approach the question by working through an example that identifies the three stages of knowledge transfer; notice, retrieve, apply (Sumeracki *et al*., 2019). This final aspect of the practical task is also designed to promote metacognition so the students mark, correct and improve their own work and set reflective targets. A reflective target could be, building confidence with using words and symbols to describe chemical events.

My school

The Talk Roles used and described in Paper 3, Chapter 3, represent specific talk moves that structure conversation. Build for example, is the move that shows you have listened to the previous statement and have additional information that adds to this point. Throughout the research the need to develop students' oracy skills has been apparent to support confidence, understanding, vocabulary, and collaboration. Providing talk scaffolds such as Talk Roles aim to encourage learners to listen and turn take rather than talk across each other.

Talk Roles have been introduced across the school to build a unified approach to oracy but uptake in lessons is slow as both teachers and students must adapt how they talk and think. To support a unified approach, I have developed and implemented the ABC approach, shown in Figure 5.4. In recognition of the importance of oracy, the school has chosen to provide year 9 students with one oracy lesson a week. I have written, resourced, and delivered this curriculum which aims to build confidence, prepare for the GCSE English spoken language assessment and to introduce public speaking and extracurricular debate.

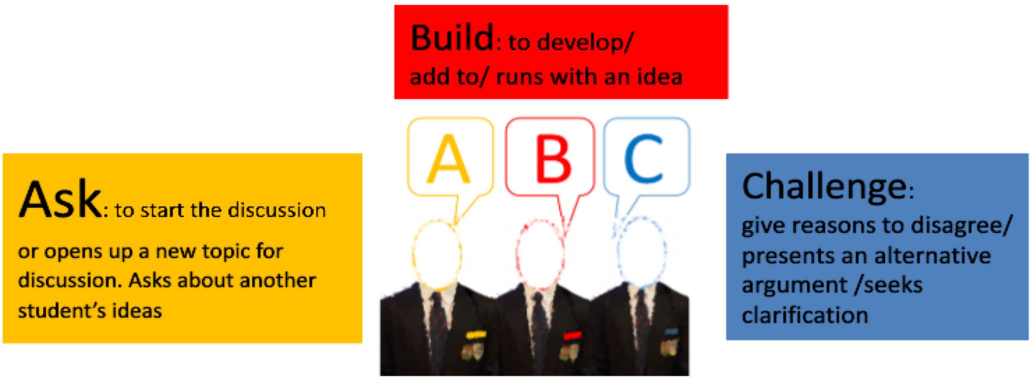


Figure 5.4, the ABC approach, my school wide approach to structuring classroom talk.

Conclusion

The overarching research question asked, “can developing oracy in the school chemistry laboratory enhance students’ learning?” and the answer to which, is yes. Oracy refers to speaking and listening skills, the ability to communicate effectively. Effective communication in the context of practical work allows students to collaborate to complete the task so that everyone has participated and everyone in the group has developed their understanding. Introducing pre-laboratory videos enabled learners to enter the laboratory with knowledge of the procedure so they had something to talk about. Oracy facilitates a student-centred approach as applying a sociocultural lens shifted my focus from the practical task to how it is operationalised. By conducting practice-oriented research and the reflexivity required to write this thesis, I have not only changed my teaching but also my worldview.

Appendix

Additional publications and research posters.

Open badges Part 1: what, why, how?

Naomi Hennah

Abstract Digital badges are graphical representations of an accomplishment. Open badges are a subset of digital badges that allow the badge owner to demonstrate achievement and the viewer to see the criteria for the badge. Open badges offer the opportunity to evidence and reward skill development, and to learn that existing formal qualifications do not. In this, the first of three articles discussing open badges in science education, the reader is introduced to the scope for using these technologies to benefit pupils, teachers and schools. Part 2 proposes a badge framework for the 'Working Scientifically' strand of the National Curriculum in England. Part 3 details a case study involving pupils aged 7–11 years in an informal education setting in which practical skills were taught overtly, using language and processes detailed in the badging framework, to facilitate the transition into secondary school science. Open badges offer the scope for explicit learning trajectories and a personalised record of skills, experience and interests to the benefit of an array of stakeholders.

The 'Working Scientifically' strand of the National Curriculum in England lays out the progression of scientific skills from key stages 1 to 4 (ages 5–16). Open digital badges offer the opportunity to recognise, evidence and reward the development of these skills. The first of this series of three articles describes open badges and their application in science education. The second article provides a comprehensive open badges framework for the 'Working Scientifically' strand of the National Curriculum. Finally, the third article details a trial using this framework to support practical skill development at key stage 2 (ages 7–11) in preparation for the demands of secondary school science education. Open badges provide a mechanism for enhancing existing assessment systems by enabling students to demonstrate their proficiency at manipulating laboratory equipment, as well as their ability to explain a practical technique in a written exam.

Open badges

Traditionally, badges have been physical artefacts that represent a judgement made by an authority regarding someone's experience, skills and knowledge. A digital badge is an image file; it can be copied and pasted by anyone to anywhere, whereas open badges must be issued. Open badges are a subset of digital badges that contain metadata embedded within the file and that provide a verifiable audit trail of the credential. Not only will an open badge contain a description of the badge, the criteria, the issuer and issue date, but also, when appropriate, standards, tags, expiry date and evidence (Figure 1). Open badges are an 'open source' technology (i.e. designed to be technically interoperable, portable and transparent) and conform to the Open Badge Standard that is shepherded by IMS Global Learning Consortium (https://openbadges.org/community/). The universal format enables an individual to earn and display badges from organisations as diverse as NASA and the National Health Service, provided that the issuer's specific criteria have been met.

Having earned the badge, the learner can then move it into their badge portfolio, called a backpack, an independent web space in which they can store their badge collection. Once the badges are in their backpack, individuals can choose which badges they want to display and where, such as on social networks and employment sites

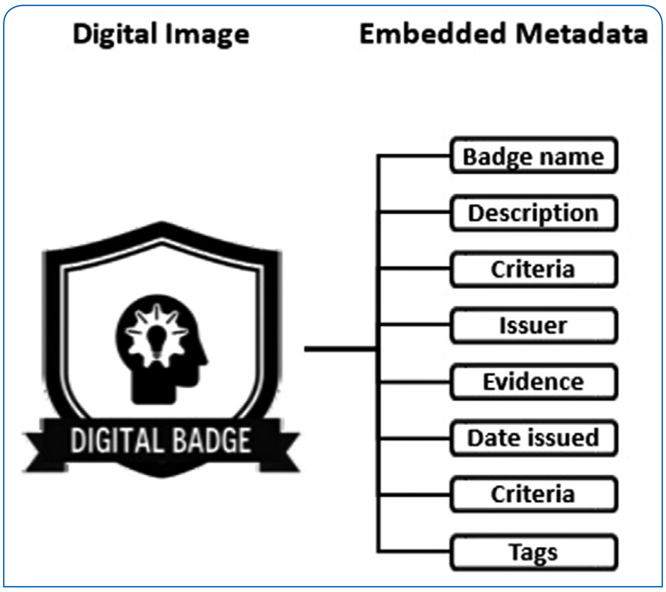


Figure 1 Open badges are a subset of digital badges that are built on free open-source software. Additional data are embedded within the image file and so clicking on the badges reveals information about the award criteria, the issuer and supporting evidence: in short, a verifiable audit trail of the credential.

or on their résumé or digital portfolio (Figure 2). Digital badges enhance digital portfolios ‘*because they can act as top-level visual organizers for the portfolio through a “learner dashboard”*’ offering ‘*a quick and powerful visual review of the student’s accomplishments… which are “media rich”*’ (Anderson and Staub, 2015).

STEM careers and open badges

The versatility and potential of open badges has attracted much interest from the science, technology, engineering and mathematics (STEM) community. Those who are already implementing open badges do so for any combination of four core purposes (see Riconscente, Kamarainen and Honey, 2013):

- fostering motivation and identity;
- expanding STEM learning areas and contexts;
- making STEM pathways visible and accessible;
- supporting selection processes.

At the 2016 British Science Festival, Siemens became the first engineering company in the UK to launch their own STEM skills programme with open badges. Siemens aim to use open badges to enrich and enhance STEM teaching and learning in the classroom and beyond to nurture engineering talent for the future (see www.siemens.co.uk/education/en/digitalbadges.htm). Open badges offer the opportunity to recognise and reward education from informal institutions such as after-school clubs, online activities, museums and NHS England (Figure 3),

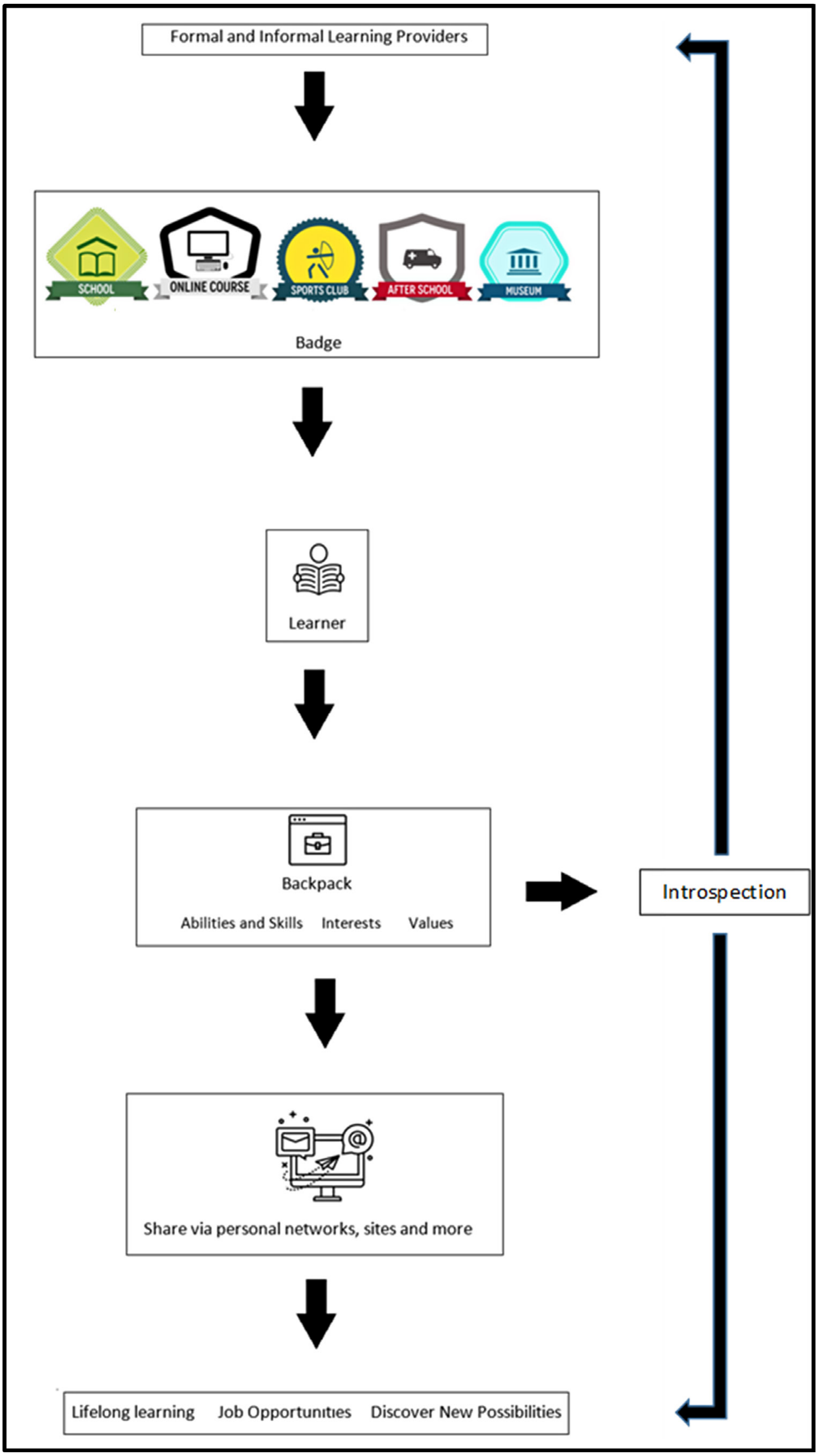


Figure 2 Using open badges to recognise and reward learning wherever it takes place, enabling self-actualisation and informed decision-making. The image shows learning being acknowledged by rewarding the learner with a badge. The badge is then added to the backpack where it is stored until the learner chooses to display it. The badge collection forms a unique aptitude profile, a visual representation of the skills they have developed, allowing the learner to identify interests to pursue or gaps to be filled. Thus, badges promote introspection and encourage students to take ownership over their learning.

Figure 3 NHS Open Badges: NHS England launched 12 digital badges for 5- to 16-year-olds – grouped into NHS Explorer, NHS Reporter, NHS Inspector and NHS Citizen and aimed at supporting children and young people's education in health and well-being. Recent research describes teachers' and pupils' positive views of the badges 'as tools that have the capacity to build perseverance, develop emotional awareness, build relationships and enhance skill and knowledge acquisition' (Alexander and Neill, 2018).

providing a mechanism of assessment that recognises and rewards learning that until now has been ignored. Research in this area is demonstrating very clearly that out-of-school STEM programmes contribute to both academic and social measures of student success (see STEM Education Coalition, 2016). When young people are helped to identify and name the skills that they develop through the activities they enjoy, wherever the learning takes place, their unique aptitude profiles will become apparent. If a young person is able to discern that they have a flair for skills as diverse as numeracy, teamwork, persistence, logical reasoning and communication, for example, they may be more likely to consider STEM careers. The current STEM workforce shortfall exceeds 40 000, reflecting a low interest in and uptake of STEM careers by young people, and yet gaming and healthcare careers are those most aspired to (see Dunn, 2016).

Traditionally, only achievements that are standardised into a course or position can be displayed. An employer looking for a chemistry graduate, for example, can see that a degree has been awarded but cannot readily ascertain whether the applicant has developed the hands-on laboratory skills needed for the post. Nor indeed are many other skills and abilities, such as creativity, communication, teamwork and problem-solving, clearly represented in traditional transcripts. Personal statements or covering letters provide the opportunity to discuss experience such as an online learning course or voluntary work for a non-profit organisation, but lack any supporting credentials. Open badges provide an eye-catching, certified way to represent learners' educational, social and personal achievements in a digital portfolio, a space where learner evidence of competencies and achievements can be stored, systematically evaluated and displayed. The inclusion of tags makes them searchable, enabling prospective employers to identify potential employees.

According to *The Right Combination: CBI/Pearson Education and Skills Survey 2016* (CBI/Pearson, 2016), '*School and college is not equipping all young people with what they need to succeed: around half of businesses are not satisfied with school leavers' work experience (56%) and their skills in communication (50%), analysis (50%) and self-management (48%)*'. In the same report, Josh Hardie, Deputy Director-General of the CBI, states that '*Skills have always been a vital currency and this is particularly pertinent as the UK carves out a new economic role in the world and begins the process of leaving the European Union.*'

Open badges in school science and between schools

Practical skill development

Practical competencies are currently assessed in England through the learners' ability to answer exam questions. Masters and Nott (1998) argue that written tests require 'explicit' knowledge (knowing what) to explain how to conduct an investigation, whereas carrying out the investigation requires knowing how ('implicit' knowledge) (p. 216). Practical work provides the context from which the implicit knowledge may be linked to explicit knowledge; to be successful in forging these links requires a 'hands-on' and 'minds-on' approach (Abrahams and Reiss, 2017: 17). Building skill proficiency 'hands-on' allows students to concentrate on procedures and purpose, 'minds-on' to support learning. Digital badges provide a mechanism to assess, reward and evidence skill proficiency throughout science education.

Consider measuring the volume of a liquid: this skill is taught in both primary and secondary school science using a range of equipment. A comprehensive badging programme could help students to recognise that the same skill is required, although the apparatus differs.

For a learner to be issued with a badge, an assessment must be made against specified criteria (Figure 4). A student is recorded using a measuring cylinder to obtain a specified volume of water, for example. The film is reviewed and assessed against badge criteria; if met, the badge can be issued, otherwise personalised feedback is provided to aid skill development. The next time a measuring cylinder is used, students without this badge can be assessed regardless of whether or not the teacher, or even the school, is the same.

Title
Measuring the volume of a liquid

Description
KS3 Measurement

This badge rewards the ability to measure the volume of a liquid by reading the scale at eye level from the bottom of the meniscus.

Criteria

Know how to select the appropriate measuring device for the volume of liquid required

Know that the divisions on different sized measuring cylinders and different equipment for measuring volume have different values.

Know that the top of a liquid forms a smile called the meniscus and that we read from the bottom of the meniscus.

Know that the reading must be taken from eye level.

Be able to safely use measuring equipment. Make sure equipment is filled below eye level -NEVER to crouch down so your head is on the same level as the table top when pouring liquid into a graduated cylinder

Be able to use the appropriate measuring unit

Be able to carry out a repeatable and reproducible measurement of volume.

Issue Date
07/10/18

Figure 4 Exemplar measurement skill badge for correctly using a measuring cylinder. Details of issuer, issue date and criteria have been included.

Cross-curricular projects

Open badges can be used to facilitate cross-curricular projects, each subject contributing experience and evidence as learners work towards a common goal. As visual symbols, badges highlight common practices, such as rearranging equations shared by science and mathematics, forging curricular links, and building learners' confidence. Recent research into the use of badges in STEM education reports *'statistically significant increases in measures of motivation including self-efficacy, self-regulation and perceived competence'* (Elkordy, 2016). Implementing an open badge framework of skills not only supports the learner, but also makes visible the school's commitment to the adoption of those factors identified by Ofsted as promoting high achievement. There are badges available, such as the O2 App Designer badge, for which an interactive design of an app idea needs to be created that could help make a difference or tackle a problem within a community, around which a cross-curricular project could be structured (see www.openbadgeacademy.com/badge/90), or departments could design, build and accredit their own badge using a digital credential service provider such as Credly (https://info.credly.com/).

Smooth transition

The September 2016 issue of *School Science Review* (*SSR*) methodically re-explored the issues that surround primary to secondary school transition believed to account for the ensuing decline in science, engagement and attainment. Resolution, it was suggested, would require science teachers either side of the interface to work collaboratively before and after the transition, to support continuity of learning and to alleviate concerns about the quality of early science learning (Collins and Reiss, 2016). A learner's badge portfolio could be shared between schools, providing not only a learning history but also evidence to support it. To make this a practical solution, a common framework is required either side of transition to avoid repetition and an increase in workload, and to provide continuity for the learner.

A common framework of the development of science skills already runs from key stages 1 to 5 (ages 5–19 in England): 'Working Scientifically'. Within this strand, there is an emphasis on both practical experience and spoken language. Yet how many educators are aware of what prior learning had occurred upon which they can build? Are learners taught to use a common language to accurately communicate prior learning? Are the learners themselves aware that the curriculum is a spiral that allows them to revisit and build upon this prior learning? If pupils are aware of their learning trajectory, they are better placed to regulate their own learning.

Coming up

Part 2 of this series of articles (Hennah, 2018), in this same issue of *SSR*, details a 'Working Scientifically' open badge framework that makes progress through the strand overt. The framework draws influence from the Ofsted

(2013) recommendations in its *Maintaining Curiosity* report: developing spoken language as a gateway to both understanding and learning, as well as the importance of practical work and practical skill development.

The final article will report on a case study, in an informal setting, with children aged 7–11 in which the methods described by the 'Working Scientifically' framework were put into practice to build practical and investigative skills in preparation for secondary school science.

Further information

Siemens and NHS England open badges can be earned through the Open Badge Academy, which hosts a library of badges available for young people: www.openbadgeacademy.com/badgelibrary.

Digital badges have been introduced in years 5–8 (ages 9–13) at Shireland Collegiate Academy in the West Midlands to accredit informal education in their Saturday School, to raise attainment by giving students the opportunity to build an online portfolio of work that can be used as a 'record of achievement' – see www.ocr.org.uk/Images/232862-digital-badges-toolkit.pdf.

The most comprehensive implementation of open badges in schools found by the author is that of the Aurora Public Schools (Colorado, USA) digital badging programme – https://sites.google.com/aurorak12.org/badge/.

The Open Badge Academy for students over 13 years of age offers a basic package that is free, whereas the more functional packages cost from £50 per month.

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Open badges Part 2: the ‘Working Scientifically’ framework

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Abstract Digital badges are graphical representations of an accomplishment. Open badges are a subset of digital badges, an image file in which additional data, metadata, are embedded. Not only will an open badge contain a description of the badge, the criteria, the issuer and issue date, but also, when appropriate, standards, tags, expiry date and evidence, thus providing a verifiable audit trail of the credential. In essence, hands-on skills, communication skills or teamwork skills can be evidenced by digital film or stills embedded within the credential. Open badges offer the opportunity to evidence and reward skill development and to learn that existing formal qualifications do not. This article describes a badge framework and suggests strategies for the ‘Working Scientifically’ strand of the National Curriculum in England science programmes of study. The badges aim to make visible the continuity of learning and development of skills from key stages 1 to 4 (ages 5–16). Emphasis is placed on spoken language to build familiarity with the language of science, to enhance thinking and to develop conceptual understanding. The framework also aims to support the development of skill mastery to reduce cognitive load and support effective practical work (Millar, 2009).

Using open badges to recognise and reward skill development

The need to recognise and reward skill development to benefit learners, educators and employers was discussed within the article ‘Open badges Part 1: what, why, how?’ in this same issue of *School Science Review* (Hennah, 2018). The infrastructure required to design, build, issue and collect badges is freely available, enabling learners to collect and share a digital portfolio of their skills and experiences. In addition to providing a visible learning trajectory within and between schools, open badges earned in other settings beyond school may also be added, providing a detailed description of learner skills and interests that can aid introspection, meta-learning and even employability.

Existing qualifications result from high-stakes summative assessment that evaluates student learning at the end of an instructional unit by comparing it against a standard or benchmark. Open badges, on the other hand, are a tool to identify and validate skills, knowledge and competencies. Elkordy (2016) reported, when using open badges, ‘*statistically significant increases in measures of motivation including self-efficacy, self-regulation and perceived competence*’ when operating within a badge framework. In England, coursework no longer exists, widening the gap between science skills and assessment. These digital badges offer the scope for explicit learning trajectories and a personalised record of skills, experience and interests to the benefit of an array of stakeholders.

The demands of language and manipulative skills can often result in working memory being overloaded; the framework suggested here aims specifically to provide opportunities to practise and work towards their mastery. Open badges for ‘Working Scientifically’ is a ‘hands-on’ and ‘minds-on approach’ (Millar and Abrahams, 2009), exploiting digital technology. ‘*The fundamental purpose of much practical work is to help students to make links between two domains: the domain of objects and observables (things we can see and handle) and the domain of ideas (which we cannot observe directly)*’ (Millar, 2009: 4). The ‘Working Scientifically’ framework aims to support the development of skill mastery to reduce cognitive load during practical work, to provide the working memory space required for effective laboratory work (Johnstone, 2006).

Open badges in education

The science programmes of study in the National Curriculum in England (Department for Education, 2015) describe a sequence of knowledge and concepts from key stages 1 to 4 (ages 5–16). As the learners progress through the key stages, ideas are revisited and built upon, to reinforce previous learning and support the passage from concrete to abstract thinking. Schools in England are required to set out their curriculum for science on a year-by-year basis and to make this information available online. Learning objectives are used to forge links between lessons, giving the learner a sense of direction within or between topics. And yet, despite adopting these measures, key stage 2 to 3 transition lacks continuity of learning (Collins and Reiss, 2016). What of the other transitions that occur within schools – are these seamless?

Introducing open badges into the science curriculum

The 'Working Scientifically' strand of the National Curriculum for science is common to all the science programmes of study, specifying the understanding of the nature, processes and methods of science for each year group. As such, this is a logical place to begin using open badges. 'Working Scientifically' open badges will give learners the opportunity to recognise fundamental scientific skills, appreciate their purpose and how they may be refined and developed over time. Making this common pathway visible and acknowledging when a skill standard has been met provides an explicit profile of a learner's prior knowledge. Prior knowledge is a key factor influencing learning and student achievement. A more detailed gauge of a student's prior knowledge better informs instructional design and curriculum planning to improve learning outcomes (Hailikari, Katajavuori and Lindblom-Ylanne, 2008).

Language

Social constructivist theory (Vygotsky, 1967) considers learning as an individual, cognitively based activity that is socially mediated. Meaning is made through socio-cultural contexts and interactions with others (Geertz, 2009); language can be thought of as a tool for learning and 'thinking together' (Mercer, 2000). Dialogic teaching methods use talk-based group activities to help develop individuals' scientific understanding, reasoning and problem-solving (Mercer and Sams, 2006). However, for group work to be effective, there should be a clear group goal and individual accountability within the group (Slavin, 1988). Furthermore, structured dialogic talk provides the opportunity to give immediate feedback: formative assessment of students' thinking to support intended learning during teaching (Black and Atkin, 2014).

Scientific language is a challenge for, or even alien to, learners (Wellington and Osborne, 2001). The complexity extends beyond unfamiliar vocabulary: polysemic words, that is words that have more than one meaning such as 'concentration' or 'cell' are confusing, and the nuances of logical connectives may be overlooked. To understand and apply this language, students need to gain mastery of it, which requires continuity, repeated exposure and the opportunity to practise and rehearse it in context until it has become lodged in the long-term memory. Almost all teaching and learning occurs through language, and thus the ability to access concepts, conceptualise practical events and construct and express meaning depends upon scientific language fluency. If the language is stored in the long-term memory, it reduces the demand on working memory (Johnstone, 2010). The framework detailed below places emphasis on talk that may be evidenced using digital technology, and talk is an effective tool for developing language and conceptual understanding (Fotou and Abrahams, 2015).

Why skill development matters in science education

Cognitive Load Theory (CLT) is increasingly employed to inform the design of learning episodes (Paas, Renkl and Sweller, 2003): in essence, if the working memory becomes overloaded, the intended learning does not occur, the length of time the information is retained decreases and opportunities for misconceptions to arise increase. Working memory will be rapidly filled when a learner is faced with verbal and written instructions containing unfamiliar vocabulary, equipment and techniques, all of which occur during practical episodes, resulting in the much maligned 'recipe-following' coping strategy so frequently employed by learners. This working memory overload means that practical work is no longer an effective link between the domain of ideas and the domain of objects and observables (Millar and Abrahams, 2009). As with students' use of scientific language, '*it is essential so to establish the manipulative skills that they can "go on auto-pilot" and free the students' attention for other things such as observation and accurate recording*' (Johnstone and Al-Shuaili, 2001). The essence of the framework proposed here is to put in place strategies that, over time, will increase the learner's familiarity with the language skills needed to learn scientific concepts, so that working memory does not become overloaded and as a result science learning and science outcomes improves.

A 'Working Scientifically' badge framework

The 'Working Scientifically' strand has been subdivided into five broad categories, each of which has its own characteristic badge. These badges make visible links between knowledge, processes and skills from different topics and subjects across the science programmes of study. Table 1 lists the five badges and the criteria to be met at each key stage. Following a badge – 'investigation', for example – through key stages 1 to 4 (ages 5–16) makes clear how the skills contained within the badge are developed and refined. Figure 1 illustrates

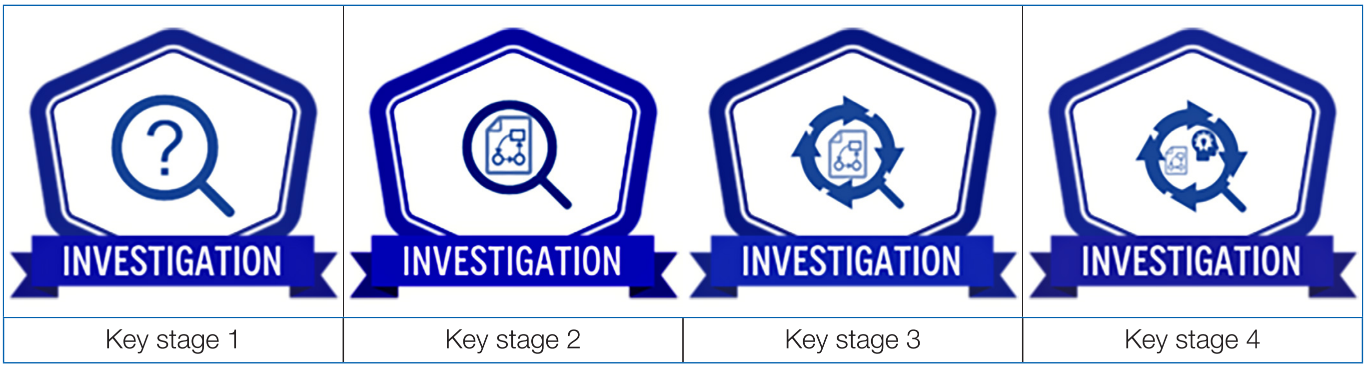

Figure 1 An illustration of how badge design, increasing in complexity, may be used to reflect development of skills as the learner progresses through the key stages

how increasingly complex badge design may be used to mirror this development and refinement of 'Working Scientifically' skills.

The National Curriculum also specifies the need to develop spoken language skills in science to support cognitive, linguistic and social development. The 'Target terms' and 'Focus points' columns in Table 1 offer guidance to support linguistic development, by providing more structured opportunities for students to talk, share thoughts and understanding. The examples provided are cumulative but subject-specific terms in higher key stages are not included. Support with the target terms from key stage 2 onwards can be found in *The Language of Measurement: Terminology Used in School Science Investigations* (Campbell, 2010) and in *The Language of Mathematics in Science: A Guide for Teachers of 11–16 Science* (Boohan, 2016). The 'Recording' column provides suggestions on how skill development may be captured, enable peer review or form the basis of group discussions to explore understanding and identify and remedy misconceptions.

Badging beyond compulsory education

The badging framework could even be expanded to incorporate the post-16 Common Practical Assessment Criteria (CPAC) as assessment of practical skills is a compulsory requirement of the course of study for A-level (ages 16–18) qualifications in biology, chemistry and physics. The CPAC appears on all students' certificates as a separately reported result, alongside the overall grade for the qualification. Open digital badges offer the opportunity to provide a more robust verification of competence, as digital evidence may be incorporated into the badge as metadata. Table 2 illustrates how the 'Working Scientifically' strand could be directly linked to CPAC to provide a seamless transition into post-compulsory science education. The third and final part of this series of open badge articles focuses on the development of measurement skills from the ages of 5 to 18 years within the English curriculum. The article reports on a case study involving key stage 2 pupils (aged 7–11) in an informal education setting in which measurement skills were taught overtly, using the language and processes detailed in the badging framework to facilitate the transition into secondary school science.

Figure 2 An A-level CPAC badge

Final thoughts

The demands of language and manipulative skills can often result in working memory being overloaded; the framework suggested here aims specifically to provide opportunities to practise and work towards their mastery. Open badges for 'Working Scientifically' is a 'hands-on' and 'minds-on' approach (Millar and Abrahams, 2009), exploiting digital technology. The framework could provide motivation to learners and be linked closely with GCSE required practical work and A-level CPAC. Digital technology offers a greater scope for evidencing student competencies using digital photographs or film instead of or in addition to written reports.

A comprehensive framework of badges would enable young people to recognise and appreciate the value of their prior knowledge. Open badges can be used to record skills acquired by an individual and as symbols that map out a learning trajectory. For example, making clear the shared characteristics of investigation skills, founded in key stage 2 (ages 7–11) and refined in key stage 3 (ages 11–14), would provide memory hooks that link concept knowledge, activities and skills, deepening learning and aiding its application in new contexts. Using open badges makes the learning pathway visible, permitting *meta learning* (Biggs, 1985) and providing continuity within and between schools. This badge

Table 1 The 'Working Scientifically' strand subdivided into five badges for each key stage

Key stage 1				
Badge	**Criteria**	**Target terms**	**Recording**	**Focus points**
Inspecting	Making systematic and careful observations including drawing diagrams.	similar different	Students take pictures to create a life cycle or storyboard to describe growth.	Increase exposure to scientific vocabulary using talk as a tool for exploring ideas and learning: Highlight terms using 'listen, repeat, make a sentence' protocol. Students use life cycle/storyboard to talk about growth. Asking questions in different ways such as, how objects are similar/different and develop keys to classify materials. Answering questions by measuring quantities and recording data in tables and bar charts. Children could compare the length and mass for themselves and be reminded that these quantities have units. Things to avoid: confusion of qualitative and quantitative data. Vocabulary pitfalls: solid is not the same as hard/rigid; big is not heavy/massive; flexible is not the same as soft. Children may have a different understanding of many words, such as material, property, object, identify. Use the word in its scientific context.
Measurement	Taking accurate measurements using standard units, using a range of equipment to determine length, volume and mass.	units	Film the activity, replay the silent film and ask students to tell you what is happening or to storyboard the method as diagrams. Baking offers an alternative context for measurement.	
Investigation	Asking relevant questions and using different types of scientific enquiries to answer them. Setting up simple practical enquiries, comparative and fair tests. Talking about ideas.	measure keep the same	Photograph different pieces of equipment and ask which could/should be used. Encourage talking about ideas between talk partners and within a whole-class group.	
Data processing	Sorting: identifying differences, similarities or changes related to simple scientific ideas and processes.	rough/smooth, hard/soft, shiny/dull; or in greater complexity: flexible/ridged, elastic (stretchy)/inelastic, transparent/opaque	Photograph objects before and after sorting and ask children to talk about the characteristics they used to sort the objects. Build a key using photographs, asking the children for the questions. Works well with small groups making a display from the different keys.	
Reporting	Reporting on findings from enquiries, including oral and written explanations, displays or presentations of results and conclusions. Using results to draw simple conclusions, make predictions for new values, suggest improvements and raise further questions. Using straightforward scientific evidence to answer questions or to support their findings.	result table bar chart key	Children film each other telling the story of the investigation – what we did, how we did it and what I think this means. Use physical gestures and actions to help structure talk and aid recall. Use images to storyboard the investigations or make an investigation jigsaw; can the children put the pieces in the right order? Children holding pictures can make a key while individuals with an object walk through the key getting sorted.	

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framework provides a means by which primary and secondary science teachers across any number of schools could work collaboratively and efficiently to support pupils' learning in science before and after transition.

Accreditation of open badges would offer schools the opportunity to identify and acknowledge skill development across the curriculum within a simple assessment system. This formal recognition of valued learning, interests and achievements could then be transferred across transition, providing a detailed profile of individuals, their skills and experience in addition to existing assessments, which in turn may bridge the gap between schools or between key stages by recognising and building upon prior knowledge to maintain engagement and augment progression. Archiving skills and achievements over long periods could help personalise career guidance, direct higher education choices and applications and ultimately guide career pathways.

Table 1 (*continued*) The 'Working Scientifically' strand subdivided into five badges for each key stage

Key stage 2				
Badge	**Criteria**	**Target terms**	**Recording**	**Focus points**
Investigation	Planning different types of scientific enquiries to answer questions, including recognising and controlling variables where necessary.	fair test variables independent dependent control categoric continuous	Photograph the equipment or lay it out and ask students to place objects into the correct place on a table of variables. Film students explaining what they are going to do using language of measurement; display the key terms clearly and check that they have been used in the correct context.	Talk remains the focus: if children can verbalise their thoughts and actions they will have a greater chance of understanding, remembering and reporting what they've done and why. The badges link with key stage 1 to show a development in the same principles, but greater complexity. The language of measurement increases at this stage. It is vital that students understand that repeating readings allows greater precision but does not affect accuracy. Repeating readings allows anomalies to be identified and excluded and provides the opportunity to calculate a mean. It is worth noting that carrying out multiple repeats and averaging does minimise random errors, hence producing a more accurate result but only if there are no systematic errors. Accuracy is about the way the experiment is conducted so that there is less room for error. The resolution of measuring equipment is unlikely to change, but the precision of the reading improves with practice. It makes sense to include these terms: control variables, so that a fair test can be explained in terms specific to the planned investigation; identify hazard and risk to encourage thinking about what could cause harm and how to reduce the risk, for example using eye protection when investigating cleavage and fracture. Evaluation provides the opportunity to reflect on what has been done and what needs to be done next. The term 'evaluate' introduces the idea that investigations are cyclic in nature; an observation leads to a prediction, 'hypothesis' could be used, which is investigated and from which data is generated and a conclusion is drawn, the investigation is evaluated to determine confidence in the outcome and further predictions can be made and so on. Warning: From year 4 there is a huge conceptual jump from physical properties and chemical reactions (macroscopic/concrete) to the states of matter models (sub-microscopic/abstract); highlight this change by identifying it and discussing it. Pitfall terms not to be used interchangeably: ● accuracy/precision/resolution; ● plastic/flexible; ● manmade/synthetic; ● transparent/clear; ● melt/dissolve/disappear. Highlight the scientific use of the following common words: solution, state, weather, natural, conduct, dissolve, reaction, burn.
Measurement	Taking measurements, using a range of scientific equipment, with increasing accuracy and precision, taking repeat readings when appropriate. Measurements: mass, volume, temperature and length.	Introduce and reinforce terms of measurement: scale, interval and units.	Ask students to each measure the same thing (video if possible), collect all their readings and discuss the spread and mean. Extension: offer choices of equipment and capture the students' reasoning behind their choices.	
Data processing	Recording data and results of increasing complexity, using scientific diagrams and labels, classification keys and tables.	Draw in pencil and use a ruler; tables have headings and units; scientific diagrams must have labels.	Provide a template that the children can use to check their own or each other's work before submitting.	
Inspecting	Using test results to make predictions and to set up further comparative and fair tests.	predicting evaluate hypothesis repeat readings fair test and variables	Opportunity for filming children's thoughts and reasoning behind a prediction (may wish to script and scaffold this) and ask the rest of the class to comment (verbally or in writing) on the extent to which they agree. Use Socratic questioning techniques to help unravel thoughts and identify misconception.	
Reporting	Reporting and presenting findings from enquiries, including conclusions, causal relationships and explanations of degree of trust in results, in oral and written forms such as displays and other presentations.	repeatable reproducible (where relevant)	Think, pair, share discussions, use mini-whiteboards for share, students walk round and collect ideas to cooperatively build a report. Wall display of different ways of reporting the results, including pro forma reports and independent work.	

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In Part 3, to be published in a future issue of *School Science Review*, find out how the strategies and ideas detailed here work with learners on the other side of transition.

Table 1 (*continued*) The ‘Working Scientifically’ strand subdivided into five badges for each key stage

Key stage 3				
Badge	**Criteria**	**Target terms**	**Recording**	**Focus points**
Investigating	Ask questions and develop a line of enquiry based on observations of the real world, alongside prior knowledge and experience. Make predictions using scientific knowledge and understanding. Select, plan and carry out the most appropriate types of scientific enquiries to test predictions; including identifying independent, dependent and control variables.	Understand and use SI units and IUPAC (International Union of Pure and Applied Chemistry) chemical nomenclature (where appropriate). accuracy precision repeatable reproducible	Use cycle templates to show the processes carried out in an investigation, provide feedback and the opportunity to improve. Then ask students to use the same cycle template to plan and organise ideas before carrying out a similar investigation (*mastery learning*).	The increased exposure to scientific ideas and practices in a laboratory environment can make students feel like they’ve not studied science before and so discount prior learning. Badging provides cohesion and evidence of progression by identification and development of scientific linking principles, ideas and experience. Continue to focus on using speech as a tool for developing thinking and collaborative learning. Encourage independence by offering writing frames and exemplar materials. These exemplar materials may be co-constructed; pupils with teacher guidance to enhance understanding wherever possible review and improve before using the same skills again. The mastery strategy: speaking together, reflecting, correcting and improving, puts focus on understanding developing practical procedures and techniques rather than just focusing on results. Understanding what’s being done and why in turn develops scientific skills and understanding of concepts. Pitfall terms not to be used interchangeably: ● mass/weight/density; ● density of material/density of object; ● substance /objects are the same thing; ● amount/mass/volume; ● element/atom/particle; ● molecule/compound/ mixture; ● displacement/strength; ● oxidation/reaction/ reactivity; ● heat/energy/temperature; ● used up/exhausted/ converted; ● sum/calculate; ● global warming/pollution/ acid rain/ozone; ● weather/climate ● sedimentary/sedentary. Highlight the scientific use of the following common words: model, substance, pure, cell, element, composition, product, reactive, bond, attraction, pure, phase, stationary, mobile, raw, resource, plate, mantle, crust.
Measurement	The continued development of measurement skills should be highlighted as new apparatus is met and mastered. Here sampling techniques are introduced for the first time: apply sampling techniques; investigate the distribution and abundance of organisms in an ecosystem via direct use in the field	random sampling transect line	Storyboard the steps for each technique/flow chart the process. Ask groups of students to write the steps on card and to hang them on a washing line in the correct order – can another group repeat the investigation using these instructions?	
Data processing	Apply mathematical concepts and calculate results. Present observations and data using appropriate methods, including tables and graphs.	line graph relationship correlation proportional inversely proportional origin slope x-axis y-axis scale, distance–time graph formula expression	Look at how close repeat readings are, decide how close they have to be and exclude outliers. Calculate a mean and use that for plotting line graphs. Ask students to co-construct an exemplar graph or mark scheme drawing on their key stage 2 learning and create a checklist that can be referred back to on future occasions. This is the ideal opportunity for cross-curricular work, offering the opportunity to have shared maths and science badges to support transfer between subjects. Ask the maths department to use the students’ science graphs in their lessons and describe the relationships seen.	
Inspecting	Interpret observations and data, including identifying patterns and using observations, measurements and data to draw conclusions. Present reasoned explanations, including explaining data in relation to predictions and hypotheses.	Reinforce the difference between observation and inference.	Role-play the story of the graph or storyboard to encourage discussion of the purpose and meaning of a graph so that children come to understand that a graph is a much easier way of describing a relationship than simply using words. Could use the ‘draw what I say’ game to demonstrate how people visualise and interpret words differently. Teach the vocabulary of graphs (work together with the maths department).	

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Table 1 (*continued*) The 'Working Scientifically' strand subdivided into five badges for each key stage

Key stage 4				
Badge	**Criteria**	**Target terms**	**Recording**	**Focus points**
Investigation	Applying the cycle of collecting, presenting and analysing data, including presenting observations and other data using appropriate methods. Using scientific theories and explanations to develop hypotheses. Planning experiments to make observations, test hypotheses or explore phenomena. Applying a knowledge of a range of techniques, apparatus, and materials to select those appropriate both for fieldwork and for investigations. Carrying out investigations appropriately, having due regard to the correct manipulation of apparatus, the accuracy of measurements and health and safety considerations.	hypothesis interval range anomalies calibration resolution errors: measurement error, random error, systematic error, zero error accuracy precision	Use exemplar video where available to encourage forward planning to make the most of bench time. Provide written method in advance and ask students to reconstruct method using images or equipment as cues or ask a group of students to demonstrate the method before the other groups begin; those observing must ask questions or intervene if the demonstration is not entirely correct. Build up to producing written plan that includes a justified hypothesis, apparatus and appropriate method to collect valid data. Developing mastery requires feedback, so film a group carrying out the investigation and ask other groups to critique their procedure and offer suggestions to improve. Ask students to use their mobile phones to film each other and swap films in groups to critique their procedure and offer suggestions to improve.	Demonstrate the use of SI units and IUPAC chemical nomenclature when appropriate. Use prefixes and powers of ten for orders of magnitude (e.g. tera, giga, mega, kilo, centi, milli, micro and nano) interconverting units. Using an appropriate number of significant figures in calculations. Reinforcing the significance of practical work is very much at the heart of the approaches described here. Time is limited so how can students prepare in advance? How can students appreciate procedure as well as result? How can students be better prepared for practical exam questions? The recording suggestions aim to begin to tackle these issues. Having had the opportunity to talk about practical work, the transition into report writing should be less onerous; encourage the use of ICT to process data and produce reports. Make the most of data collection to highlight why scientific method has developed in this way: look at the raw data; discuss what can be seen, then process the data (collect class results to find a mean for example). Plot graph as results are collected to allow identification and exclusion of anomalous data, allowing for effective repeat collection. Discuss the parameters for including or excluding a result. Highlight the differences between student results and textbook results; don't ignore wrong results, instead explain why it is appropriate to discount their evidence. Exemplar videos or retaining videos made by the students could be reused during revision. Set a question to ask before the video is watched and ask students to mark/ correct /improve their answers afterwards. Activities such as these, which provide the opportunity for reflection and development before moving on, align with *mastery learning* (Bloom,1971).
Measurement	Using an appropriate number of significant figures in calculations, translating data from one form to another. Carrying out and representing mathematical and statistical analysis.		Ensure individual measurement and technique badges are being applied. Encourage students to narrate their practical work. Where possible select a range of apparatus with increasing resolution and ask students to guess the value of the measurement each time the resolution is increased. This builds familiarity with the term and understanding of its significance. Ask students to weigh masses using a weigh boat and then a beaker; discuss the effect on the measured value.	
Inspecting	Evaluate risks and use appropriate techniques, apparatus and materials during fieldwork and laboratory work, paying attention to health and safety.	risk hazard strength concentration	Students to identify hazards and the risks associated with the hazard. Introduce and use hazard symbols and encourage students to consider what signs could be used and why they may not be (such as low concentration of acid). Introduce and use appropriate resources such as CLEAPSS Student Safety Sheets: encourage students to use them for research before and reference them after the episode to identify hazards and highlight safety precautions that mitigate risk.	

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Table 1 (*continued*) The 'Working Scientifically' strand subdivided into five badges for each key stage

Key stage 4 (*continued*)				
Badge	**Criteria**	**Target terms**	**Recording**	**Focus points**
Data processing	Communicating the scientific rationale for investigations, including the methods used, the findings and reasoned conclusions, using paper-based and electronic reports and presentations interpreting observations and other data, including identifying patterns and trends, making inferences and drawing conclusions, presenting reasoned explanations, including relating data to hypotheses.	line of best fit origin gradient rate constant reciprocal inverse inversely proportional equation formula expression	Use ICT to process data and produce a report that identifies patterns and draws conclusions with a reasoned explanation that relates the data to hypotheses. Divide students into small groups, tasking individuals to draw the graph or make inferences or evaluate so that between the groups the data are fully processed.	
Reporting	Evaluate the reliability of methods and suggest possible improvements. Evaluate data in terms of accuracy, precision, repeatability and reproducibility and identifying potential sources of random and systematic error.	random error systematic error reliability resolution precision accuracy certainty true value uncertainty validity valid conclusion	Use 'show me' boards or think-pair-share to draw out predicted trends, put these aside while results are collected and then compare and contrast the two. Turn and compare with another group and decide if the results were repeatable and/or reproducible. Discuss differences between results and trends: how could these have arisen? Record how the prediction was made (evidence used). Record how the results were compared with prediction and if any further investigation is needed to support or refute the conclusion.	

Notes

Further discussion of the impact of dialogic pedagogy in science education can be found in Ruthven *et al.* (2017).

Oracy Cambridge (www.educ.cam.ac.uk/research/projects/oracytoolkit/) and Voice 21 (www.voice21resources.org/) both offer free materials to support and assess dialogic teaching.

Digital badges designed and made on free-access Credly (https://credly.com/).

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Table 2 Post-16 science education CPAC

Badge	Criteria	Target terms	Recording	Focus points
Investigation	Correctly follow written instructions to carry out experimental techniques or procedures. Apply investigative approaches and methods when using instruments and equipment.	scale drawing scalar vector algebraic equation formula expression coefficient order of operations subject of a formula proportional directly proportional constant of proportionality linear relationship linear equation exponential relationship inverse square relationship rate intercept gradient tangent	Ask students to describe what they are going to do before beginning. Film a walk-through method, watch back looking for omissions, identify and analyse mistakes. Encourage students to watch exemplar videos before the lesson, perhaps draft their own method, storyboard or annotate the method provided. Revisiting the exemplar video can reinforce understanding and aid exam revision. Use mobile phones to record their own investigations and then analyse the videos to identify good practice and areas to develop, providing the opportunity to reflect on their own manipulative skills, drawing meaning to the process rather than completely focusing on the result. Use of a lab book to document the practical work. Include (where appropriate) method sheets, their own method, links to videos and photographs as well as results and analysis. Focus is given to a particular aspect of the write-up in most cases, such as analysis or methods writing, to avoid overwhelming the students or limiting the practical episodes experienced. At times the analysis will be limited to answering the questions given on the method sheet or may be much less scaffolded. Encourage students to compare hand-drawn graphs with those they produce on computers; highlight advantages and limitations of both. Where appropriate include error bars.	Make the most of practical work by providing opportunities to prepare before carrying out the investigation, watching exemplar videos discussing techniques or questioning the procedure used. Bench time is limited so must be used effectively; good preparation and targeted analysis will help achieve this. The use of badging will help focus ideas and link practical and theory more closely by employing the investigation cycle developed earlier. Ensure observations are recorded using scientific description and units. Distinguish clearly between observation and inference. Encourage talk about choice of methods such as when to tare the balance compared with weighing by difference. Whenever possible give examples of techniques being used in the real world. Enforcing the use of lab books to document all investigations but particular emphasis on the skill to be badged. Develop an understanding that a lab book is more than a record of what was done but is also a: source of data that can be referred to; complete record of what has been done so that the experiment may be reproduced; tool to support thinking and questioning results so that they may be interpreted fully. Note about references: there are a number of ways to document sources through in-text references; it is important to use the same method throughout a document and include a reference list at the end. Structure of a lab book: the following format will provide evidence of investigations and interpretation of results: title and date of experiment, notes on what the objectives of the experiment are, notes on the method, including all details (e.g. temperatures, volumes, settings of pieces of equipment) with justification where necessary, sketches or photographs of how equipment has been set up, tables prepared in advance to input data and observations while carrying out the experiment, calculations – annotated to show thinking, graphs and charts, summary, discussions and conclusions and a cross-reference to earlier data and references to external information.
Inspecting	Identify hazards and assesses risks. Safely use a range of practical equipment and materials including use of appropriate safety equipment and approaches to minimise risks with minimal prompting.			
Measurement and observation	Make accurate observations relevant to the experimental or investigative procedure. Obtain accurate, precise and sufficient data for experimental and investigative procedures and record this methodically using appropriate units and conventions.			
Reporting and data processing	Use appropriate software and/or tools to process data, carry out research and report findings. Cite sources of information demonstrating that research has taken place, supporting planning and conclusions.			

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Open badges Part 3: framework and strategies in action

Naomi Hennah

Abstract Open badges are portable, digital credentials that offer the opportunity to reward learning in both formal and informal settings, providing an inventory of competencies and interests. Previously, a comprehensive framework of open badges in the 'Working Scientifically' strand of the National Curriculum in England (ages 5–16), extending into post-16 study of science, has been described. Here the case for both teaching manipulative and procedural competencies and how to do so is demonstrated. The trial implements the open badge framework and strategies in an informal setting. Evidence from film recordings made during the trial suggests that this strategy can be used successfully to motivate and engage young people, to develop fundamental practical skills and to introduce and reinforce key scientific vocabulary in a more overt manner than is currently used in school education.

Using open badges to reward formal and informal learning

In September 2018, the Education Endowment Foundation (EEF) published their recommendations for improving secondary science; these include purposeful practical work, self-regulation, memory and the language of science. All of these and more have been discussed in the first two of this trilogy of articles, which considers a joined-up approach to 'Working Scientifically' from age 5 to 18 and culminates in this final article that both maps the named apparatus and techniques and also describes the pedagogy in action.

Part 1 of this series (Hennah, 2018a) explained how open badges could be implemented to improve existing assessment systems. Open badges are a subset of digital badges in which the image file of a digital badge is embedded with metadata such as a description of the badge, the criteria, standards and digital evidence. The badges can be used to map learning trajectories, add incentive and reward achievement within or between schools. Furthermore, this technology can help build learners' science capital (Archer *et al.*, 2015) by offering the opportunity to recognise and reward out-of-school STEM programmes, which have been shown to contribute to both academic and social measures of student success (STEM Education Coalition, 2016).

In Part 2 of the series (Hennah, 2018b), an open badge evidence and assessment framework was described. The framework considers the 'Working Scientifically' strand of the science National Curriculum in England, harnessing digital technology to evidence student competencies and make visible the continuous development of the strand from key stage 1 (age 5) through to post-16 science education (up to age 18). The framework provides: success criteria vital for both feedback and self-regulation; the opportunity to recognise, motivate and reward the development of students' competencies (Jovanovic and Devedzic, 2015); and appropriate information about prior knowledge to improve curriculum planning.

This article looks in more detail at why the framework advocates the development of practical procedure competency and manipulative skill mastery and how ultimately this can benefit students, teachers and schools. Following this, consideration is given to structured talk as a tool for developing vocabulary, building understanding and supporting effective group work.

This article seeks to demonstrate the use of these strategies detailed in the framework, although they could be employed with existing schemes of work. The activities that are described in this third part are applicable to ages 11–13 as ways of introducing practical science during introductory science lessons or on taster days prior to transition at age 11. In the description that follows, however, the activities were trialled with a group aged 7–11 in an after-school club.

Developing practical procedure competency and manipulative skills

'Working Scientifically' specifies the understanding of the nature, processes and methods of science (Department for Education, 2015). One aspect of this work involves investigating, gathering and recording data to help in answering questions, exploring ideas or looking for patterns that require interpretation rather than establishing definite fact. Measurement was one of the five badges named in the framework (Hennah, 2018b). Table 1 provides a map

Table1 A map of the science subject-specific apparatus and techniques named in the science programmes of study and the A-level Common Practical Assessment Criteria (BIO = biology, PHY = physics, CHE = chemistry, KS = key stage)

Apparatus and techniques	A-level BIO	KS4 BIO	A-level CHE	KS4 CHE	A-level PHY	KS4 PHY	KS3	KS2	KS1
Measurement of:									
mass	×	×	×	×	×	×	×	×	×
time	×	×	×	×	×	×	×	×	×
volume	×	×	×	×	×	×	×	×	×
temperature	×	×	×	×	×	×	×	×	×
length	×	×	×	×	×	×	×	×	×
pH			×	×			×		
reaction rate			×	×					
pressure					×				
force					×	×	×		
angles					×	×	×		
area						×			
motion					×	×	×		
current					×	×	×		
voltage					×	×	×		
resistance					×	×			
Interpolate	×		×	×	×	×			
Heating	×		×	×			×		
Colorimetry	×		×						
Serial dilution	×	×							
Microscopy	×	×					×		
Graticule	×								
Hand lens							×	×	×
Chromatography	×		×	×			×		
Sampling	×	×					×		
Datalogger/digital instrumentation	×		×		×	×	×	×	×
ICT	×	×	×	×	×	×	×	×	×
Qualitative tests (organic/inorganic)	×	×	×	×			×		
Crystallisation				×			×		
Recrystallisation			×						
Melting point apparatus			×						
Standard solution			×						
Titration			×	×					
Distillation			×						
Electrochemical cells			×						
Electrolysis				×			×		
Organic preparation			×						
Separation			×	×			×	×	×
Light source or laser					×	×	×	×	
Circuit building					×	×	×	×	
Ionising radiation					×				
Investigating waves					×	×			
Signal generator and oscilloscope					×				
Calipers/micrometers					×				

of the science subject-specific apparatus and techniques named in the science programmes of study (Department for Education, 2015) and the A-level Common Practical Assessment Criteria (Assessment and Qualifications Alliance, 2017), demonstrating the fundamental importance of measurement procedures in the English science curriculum.

The development of manipulative skills, such as those required when taking measurements, is one important aim of practical work (Abrahams, Reiss and Sharpe, 2013). According to R. F. Kempa (1986) as cited in Fadzil and Saat (2017), manipulative skills can best be defined as psychomotor skills that relate individual cognitive function to corresponding physical movement. Fadzil and Saat (2017) suggest that manipulative skills acquisition is hierarchical, the students' advancement to the next level of skills depending on their achievement of the lower level of technical skills. Thus, for practical work to be 'effective' (Millar, 2009), students need to be taught the manipulative and procedural competencies required to carry out practical work. Furthermore, Johnstone and Al-Shuaili (2001) reported that students who are competent in science manipulative skills will be better able to concentrate on the development of science process skills, such as observing, measuring and using numbers, inferring, predicting, communicating, using space-time relationship, interpreting, defining operationally, controlling variables, making hypotheses and experimenting.

The English GCSE science grade descriptor for level 8 and 8-8 states that students can '*critically evaluate and refine methodologies, and judge the validity of scientific conclusions*' (Office of Qualifications and Examinations Regulation, 2017). Meeting these criteria requires more than an exposure to practical work and apparatus: it demands an understanding of how and why it is used. Coelho and Séré (1998) explain that practising measurement procedures and experiencing measurement variability encouraged students to think about their measurements, considering problems such as spread, precision, accuracy and the 'true value' of the measurement, and associating uncertainty with the instrument graduation. Thus, developing competency in measurement procedures may in turn help students to evaluate their methods and suggest improvements.

The use of digital badges to recognise, and reward laboratory practical skills has already been reported in university with chemistry undergraduate students (Seery *et al.*, 2017), in secondary school with A-level chemistry students (Hennah and Seery, 2017) and with GCSE chemistry students (Hennah, 2019) but not (until now) with younger students, nor in informal settings. Digitally recording activities increases the opportunity to provide feedback and allows the learner to examine their own practice and that of others and so appreciate nuance of technique. This strategy of rehearsal and feedback is described as '*mastery learning*' (Bloom, 1971). Open badges offer the opportunity to use ICT to recognise, evidence and reflect upon learning, empowering students to direct their own learning.

Socio-cultural theory and the laboratory

Vygotsky's socio-cultural theory of learning (Vygotsky, 1978) describes learning as occurring on two levels: through interaction with others, and then integration into the individual's mental structure. Such mental structures are schema, the cognitive patterns of thought and knowledge that help us remember and retrieve information. From this perspective, social interaction is fundamental to the development of cognition: asking questions or discussing activities can activate schema ready for storing new related knowledge (Anderson, 2013). Furthermore, Vygotsky theorised that cognitive development is limited to a '*zone of proximal development*' (ZPD), an area in which the learner is cognitively prepared but still requires help and social interaction with a more knowledgeable other to develop fully. Mercer (1995: 1) describes this communication process, in which one person helps another person to develop their knowledge and understanding, as the '*guided construction of knowledge*'. Talk is a tool for reasoning and talk-based activities can scaffold the development of reasoning and scientific understanding (Rojas-Drummonda and Mercer, 2003).

Dialogic teaching is a pedagogy that recognises learning as a social process, using structured talk to guide students in constructing knowledge. The teacher assumes the role of a facilitator of the learning process rather than the source of knowledge, providing the instructional supports, the scaffolding, necessary to complete the task successfully.

As practical tasks in science offer the opportunity for dialogue and group work, structuring talk can help students conduct coordinated group work, manage divisions of labour, and aggregate and compare results, all of which are fundamental aspects of 'Working Scientifically'. Furthermore, when students are able to work effectively as a group, the cognitive load imposed by a complex task can be reduced and learning aided (Kirschner, Paas and Kirschner, 2009).

Key stage 2 after-school club trial

Having introduced open badges as a technology that can be used in both formal and informal learning environments (Hennah, 2018a) and having proposed a framework that can be used with learners from ages 5 to

18 (Hennah, 2018b), this work seeks to put these assertions to the test. The application of dialogic teaching and the development of practical competencies and manipulative skills, as described in the open badge 'Working Scientifically' framework, were trialled in an informal learning setting with young people aged 7–11 years. The activities were offered as part of an after-school programme open to all the key stage 2 students in the school.

The appropriate permissions were sought through the school management, with information about the purpose of the research, what data were being gathered and the right to withdraw. Permission to record the students during the sessions was obtained to adhere to the school safeguarding policy. None of the video footage or images could be removed from the school premises, so all the analysis took place on site. Funding was provided by the Royal Society of Chemistry East Midlands Local Section Trust for purchasing consumable materials. Additional scientific equipment was kindly loaned by Northampton School for Boys.

The research question was:

Can the open badge 'Working Scientifically' framework be used with key stage 2 students in an informal education setting?

Specifically, can the students demonstrate competencies described in the following open badge criteria:

- **Investigation badge.** Students should develop their understanding of the scientific approach to enquiry (Figure 1).
- **Measurement badges.** Students should learn how to use a piece of laboratory equipment to measure each of the following accurately: time (s), volume (cm^3) and mass (g) (Figures 2–4).

Key stage 2 Investigation

This badge has been awarded in recognition of demonstrating the ability to plan an investigation that allows valid results to be produced.

Criteria:

- Asking relevant questions and using different types of scientific enquiries to answer them.
- Setting up simple practical enquiries, comparative and fair tests.
- Talking about ideas.

Figure 1 Investigation badge and award criteria

Key stage 2 Mass measurement

This badge rewards the ability to use a 0.0 g electronic balance correctly to obtain an accurate mass in grams.

Criteria:

Demonstrate:

- how to check a balance is clean;
- how to set your balance to zero;
- how to use a weigh boat and reset the balance to zero;
- that the weigh boat is removed from the balance while solid is added;
- that a small quantity of solid is added and that the mass is checked before adding more.

Figure 2 Mass measurement badge and award criteria

Key stage 2 Time measurement

This badge rewards the ability to use a digital stop clock to time events to the nearest second.

Criteria:

- The stop clock must be reset to zero.
- A repeatable start and end point must be used to allow accurate times to be recorded.

Figure 3 Time measurement badge and award criteria

Key stage 2 Volume measurement

This badge rewards the ability to measure the volume of a liquid in a 25 cm^3 measuring cylinder by reading the scale at eye level from the bottom of the meniscus.

Criteria:

- Know that the top of a liquid forms a smile called the meniscus and that we read from the bottom of the meniscus.
- Demonstrate that the reading must be taken from eye level with the measuring cylinder sat on a flat surface.
- Demonstrate filling the measuring cylinder below eye level with the measuring cylinder sat on a flat surface.

Figure 4 Volume of a liquid measurement badge and award criteria

Trial method

Over five sequential sessions, 18 students, aged between 7 and 11 years, were introduced to scientific measuring apparatus and how to use it. The activities were planned with the Practical Activity Analysis Inventory (PAAI) (Millar, 2009), as a means of assessing the activities' effectiveness in meeting the intended outcomes: developing student competencies to meet the criteria described by the badges. The activities (Table 2) were selected so that measurement procedures were introduced in one week and then revisited, but applied in new contexts, in the following weeks. The final keystone session provided the opportunity for the students to showcase their 'Working Scientifically' competencies and to be assessed against the badge criteria.

Table 2 The activities carried out during the after-school club sessions, detailing the quantities measured and the measurement procedures introduced and revisited

<table>
<tr><td>Week 1
Making salt dough

Measurement focus:
Mass (g)</td><td>Look at a broad range of equipment used to measure mass, volume and time:
Group them and discuss why there are so many.
Demonstrate and discuss:
• clean the balance;
• check units;
• zero the balance with the weigh boat (plastic cup);
• demonstrate how to use a weigh boat and balance, removing the weigh boat to add solid so the balance remains clean.
Student task:
Can your group measure out the following:
100 g flour, 50 g salt, 50 cm^3 warm water, 2 cm^3 oil.
Mix together. Have you made dough?</td></tr>
<tr><td>Week 2
Giant bubbles

Measurement focus:
Volume (cm^3)</td><td>Discuss choosing the best pieces of measuring equipment:
Check the capacity is close to the volume to be measured so that the value of the graduations (marks) is as small as possible (highest resolution).
Filling a measuring cylinder:
Does the meniscus sit on the mark when viewed at eye level?
Student task:
Every member of the team must check and agree the volume measurements before their mixture is made. Each group was initially assigned one mixture to make. The mixture chosen as the best one was then made by all the groups and used to make giant bubbles.
<table>
<tr><th>Group</th><th>Volume of water (cm^3)</th><th>Volume of washing-up liquid (cm^3)</th><th>Volume of glycerine (cm^3)</th></tr>
<tr><td>1</td><td>193</td><td>3</td><td>4</td></tr>
<tr><td>2</td><td>192</td><td>6</td><td>2</td></tr>
<tr><td>3</td><td>190</td><td>6</td><td>4</td></tr>
<tr><td>4</td><td>193</td><td>6</td><td>1</td></tr>
<tr><td>5</td><td>191</td><td>6</td><td>3</td></tr>
<tr><td>6</td><td>194</td><td>6</td><td>0</td></tr>
</table>
Test best bubble mixture:
Glycerine or no glycerine and volume of washing-up liquid.
(Based on: www.rigb.org/families/experimental/giant-bubbles.)</td></tr>
</table>

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Table 2 (*continued*) The activities carried out during the after-school club sessions, detailing the quantities measured and the measurement procedures introduced and revisited

<table>
<tr>
<td>Week 3
Slime

Measurement focus:
Mass (g)</td>
<td>Look at a broad range of equipment used to measure mass and volume:
Ask students what the best piece of equipment is to measure:
an egg, 150 cm^3 milk, a 5p coin and 5 cm^3 of water.
They need to make a choice of the correct-sized cylinder, which depends on the volume required.
Practise using a balance and weigh boat:
How much support is required?
Student task:
Decide which ratio of cornflour to water is best. Water is the independent variable; cornflour mass is controlled.
<table>
<tr><th>Test</th><th>Cornflour (g)</th><th>Water (cm^3)</th></tr>
<tr><td>1</td><td>5</td><td>5</td></tr>
<tr><td>2</td><td>5</td><td>4</td></tr>
<tr><td>3</td><td>5</td><td>3</td></tr>
<tr><td>4</td><td>5</td><td>2.5</td></tr>
<tr><td>5</td><td>5</td><td>2</td></tr>
<tr><td>6</td><td>5</td><td>1</td></tr>
</table>
</td>
</tr>
<tr>
<td>Week 4
Cannons

Measurement focus:
Time (s)</td>
<td>Introduce predicting and estimating:
<i>Ready steady hands up:</i> Student stands with arm in the air and lowers when they think a minute has passed. Time them and tell them how close their estimate was.
Now ask students to estimate 1 g of sodium hydrogen carbonate in a weigh boat; then weigh their estimate.
Student task:
Pour 5 cm^3 ethanoic acid into film canisters and then add sodium hydrogen carbonate in a twist of toilet paper. Put the lid on and start the timer.
<table>
<tr><th></th><th>Volume of ethanoic acid (cm^3)</th><th>Mass of sodium hydrogen carbonate (g)</th><th>Time for cannon to fire (s)</th></tr>
<tr><td>1</td><td>5</td><td>0.5</td><td></td></tr>
<tr><td>2</td><td>5</td><td>1</td><td></td></tr>
<tr><td>3</td><td>5</td><td>1.5</td><td></td></tr>
</table>
Goggles must be worn. Cannons fired forward, not at people or up in the air
Estimate how long 2 g sodium hydrogen carbonate would take and then try it.</td>
</tr>
<tr>
<td>Week 5 (keystone)
Cannons

Planning an investigation and taking measurements:
Volume (cm^3)
Mass (g)
Time (s)</td>
<td>Ask students to demonstrate and explain:
• how to read a measuring cylinder;
• using a transfer pipette to ensure the bottom meniscus is sitting exactly on the required level;
• how to use a stop clock, ensuring same start point and same stop point are used;
• how to use a balance correctly to avoid spillage and damaging the balance.
Student task:
Designing an investigation.
Pre-test: Use the quantities given to check that the cannon can be fired.
Scientific investigations are carefully planned to answer one question. In groups you need to decide what question you will ask. How are you going to find the answer to that question?
Carry out your three experiments using new measuring skills. What did you find out?
<table>
<tr><th>Volume of ethanoic acid (cm^3)</th><th>Mass of sodium hydrogen carbonate (g)</th><th>Time for cannon to fire (s)</th></tr>
</table>
</td>
</tr>
</table>

The students were shown the badges and the criteria to be met before the badge could be awarded. It was explained that the sessions would be filmed and that they would be asked to demonstrate how to measure things and asked questions about what they were doing so that everyone had an opportunity to earn the four badges. After the fifth week, any badges that had been earned would be displayed on certificates and awarded to individuals during their school assembly.

The students were supported by three adults, only one of whom had teaching experience. The researcher, an experienced secondary school science teacher, began and finished each session, presenting, demonstrating and discussing the activities with all the students. In addition, the students were reminded which badges formed the focus of that week and the criteria they had to meet to earn them. Each session was filmed using the school iPads by two adults and each of the student groups. The staff were given scripted scaffolding questions (Table 3) to structure their talk with students. This semi-structured interview approach afforded every group the same opportunity to explore their understanding of the activity regardless of the staff member asking the questions.

Following each session, all the films were watched and coded for evidence of good technique, use of target vocabulary, and the ability to answer scripted questions. The videos were also used to inform interventions if, for example, a group had been seen to struggle with planning, manipulative skills or target language. The student groups were interviewed by different staff members each week to reduce bias. The films made by the groups were examined for evidence that the correct procedure and scientific terminology was being used without adult intervention.

Trial outcomes

All 18 students were awarded the measurement badges (Figures 2–4) by demonstrating that they could meet the specified criteria. In addition, each of the six student groups worked together to meet the criteria of the key stage 2 investigation badge (Figure 1). The assessments were made based on video evidence of individuals' manipulative and procedural skills and semi-structured interviews.

When the students were asked initially to select which equipment they could use to measure liquids they were able to do so. The students indicated that the

Table 3 Scripted questions to scaffold semi-structured interview with student groups to support talk about what they are doing and why

Making salt dough	**Vocabulary:** Measuring cylinder, transfer pipette, balance, weigh boat, mass, volume. **Scripted questions:** Why did we check the balance was clean? Why did we zero the balance with the weigh boat? How do we add the flour to the weigh boat? What happens if you use too much? What happens if you spill it? Why do you think we want to keep the balance clean? What do you think happens if you press the balance buttons before you have the correct mass? What could you do to get the correct mass? Tell me about your dough (how did it feel). What does this tell you about your measurements? How could you make the dough better?
Giant bubbles: making and comparing bubble mixtures	**Vocabulary:** Criteria, fair test, independent variable and control, volume, measuring cylinder, meniscus, eye level. **Scripted questions:** What equipment do you want to use? Why did you choose that? What is the name for the 'smile' the water makes at the top? Show me how to measure the water. Was that the best way? Look from above and then below. What happens? Look at the glycerol. Is it like water? Do you remember how we measured the oil last week? Can you show me? How can we decide which the best mixture is? What is your independent variable? What was controlled? What will you use to measure the water? Can you show me how to do that? Why did you choose the 100 cm^3 measuring cylinder? What happens if you used the 10 cm^3 measuring cylinder nine times instead? What did you find out? Did you all agree? How would you decide if your bubble mixture is good?
Making slime	**Vocabulary:** Independent variable, predict, result, fair test, criteria, mass, volume. **Scripted questions:** Students discuss in their team how to choose the equipment required. How do you use it? Look at the 0.0 g balance. Which number needs to be a 5 so the balance reads 5 g? If the balance reads 5.5 g what does that mean? Can you use this mass instead of 5 g? Why do you think that? Show me how you get ready to use the balance. Why do you think a weigh boat is used? What must you do to the balance before you begin? Why are they doing it in that way? Where do we add the solid to the weigh boat? Can you show me what you think 1 g of cornflour looks like? [*Check the student has put the empty boat on the balance and pressed zero, and then removes the boat from the balance to add solid.*] Now add what you think is 1 g of cornflour to the weigh boat and place the weigh boat on the balance. How close were you? What happens if you press zero before you finish? Can you show what to do now? If you are cooking and you spill the flour on the floor what do you do? Why don't you put the flour in the bowl? Is it OK to use the spilt flour here? What was the independent variable (thing you changed)? What happened? Was this a fair test? Why do you think that? Does everyone agree? What else could we do with the slime? Why would you choose to do that? What effect would that have on the slime?

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Table 3 (*continued*) Scripted questions to scaffold semi-structured interview with student groups to support talk about what they are doing and why

Cannons	**Vocabulary:** Predicting, estimating. **Scripted questions:** How close were you to 1 minute? If you try it again do you think you would be closer? How could you get better at estimating a minute? When you were estimating mass, what did you do first (zero the balance and weigh boat)? If you didn't do this what happened? How do you think you could measure the real mass without starting again? What happened when you saw the sodium hydrogen carbonate powder being added to the ethanoic acid? Can you predict what will happen when the reaction takes place in the film canister with a lid on it? What did you do with the sodium hydrogen carbonate before it was put in the acid? Why was the paper needed? If you forget to use the paper what happens? Will the time be different if paper is used? Why is this a fair test? What if I use different types of paper; how would that change the results? Can you give me an example? What is different about that paper?
Planning and conducting a cannon investigation	**Scripted questions during planning:** What is the question you are trying to answer? What will be controlled (kept the same)? What is changed (independent variable)? What will you measure (dependent variable)? Can you predict what you think will happen? **Scripted questions following the investigation:** What would you like to tell me about your investigation? How do you know you have started the timer at the same point each time? If I point my cannon up in the air will I get the same time as if it lies on its side? What else could we try? If you change the volume of acid and the mass of sodium hydrogen carbonate how will your results compare to these ones? Look at other groups' results. Are they the same? Why? Based on your understanding of a fair test, explain to me how good you think your results are? What would make them better? What would make them worse? [*A canister lying on its side allows acid to run out when the lid bursts open. A waterproof sheet was used to funnel (most) of the spillage into a bowl. The activities were in the school hall so I had to be very careful about slippery floors. I used old table cloths brought from home – all very DIY but effective.*]

liquid measures had a spout for pouring, indicating an ability to identify parts and functions of apparatus, even when it is unfamiliar. However, the correct handling of the apparatus was less intuitive. Choosing volume measurement again as an example, the students were seen to try filling and reading measuring cylinders while they were being held up. Following a demonstration of the technique and a discussion of safety, the students were seen to place the measuring cylinders on the table and to view the meniscus from eye level, although some individuals persisted in twisting their necks rather than crouching to achieve this.

An understanding of the basic principles of using and handling apparatus was presented as a set of rules to follow to ensure the correct result is obtained. If the rules are not followed, the students were taught that safety and the results of the investigation were at risk. So 'Working Scientifically' means taking precautions to ensure reliable observations and results can be obtained.

The videos made by the students varied in quality and content; two of the groups were seen to enjoy enacting the role of science video presenters and as such displayed a good use of technique and vocabulary. There were a few issues with starting stop clocks appropriately but, as the course progressed, timing and volume measurement showed a marked improvement in meeting the specified criteria. Using a balance and weigh boat was less successful and required frequent reminders. The films revealed that in most cases the weigh boat was not removed from the balance when adding the sample. One group continued to make a measurement after spilling flour outside the weigh boat onto the balance and recorded the total mass even though only the contents of the weigh boat were transferred for use, suggesting that the significance of the procedure was not understood.

Reviewing the films revealed that the students enjoyed rehearsing new vocabulary. The word *meniscus* had an attraction for the students and was used frequently and appropriately with emphasis. The terms *independent variable* and *controlled* were used correctly without prompts by most groups. Students' understanding was demonstrated most clearly when scaffolding, through scripted questions, was used, along with guided instruction to encourage reflection. Prompts were provided so that turn-taking occurred. Some students were seen to act as guides, supporting others to carry out tasks or answer questions, assuming the role Vygotsky (1978) describes as a more knowledgeable 'other'. In this way, the planning of the keystone experiment was successful, but most groups needed to be reminded to only change one variable.

This trial indicated that the criteria outline by the four badges (Figures 1 to 4) could be met and that video could be used to evidence the students' competencies. Furthermore, the use of scripted questions to scaffold conversations with the students was an effective method for eliciting the children's ideas about the procedures and provided the opportunity to evidence the correct use of target scientific vocabulary. It was also interesting to watch the recordings made by the student groups and find some evidence that the techniques and vocabulary were being used without adult intervention. Overall the students' measurement skills were seen to develop and use of target vocabulary was evidenced. Using video added an additional level of engagement, the students reporting that they felt like real scientists. Four parents commented that their children were enjoying the activities. One also relayed that her son felt that he was learning to be better a scientist ready for his next school.

Limitations

During the trial, it was not possible to use the badges as a digital record of the students' work, as a suitable, safe, infrastructure was not available; also, retaining images or recordings of the students went against the school safeguarding policy. It is worth noting that a school or academies could use the open badge technology within their own network. In this trial, the digital badges were issued directly to the school via email, providing the school with a record of the work undertaken, and it was agreed that the students could be issued directly with certificates displaying digital images of the accreditation. The badges still provided the students with an incentive, as demonstrated by students asking, '*Was that good enough for the badge?*' The badges earned by the students were displayed on certificates, symbols recognising and rewarding their ability to meet the specified criteria. The head master asked the students about the badges and what they had done, as he presented the certificates in a school assembly. Receiving the certificates in assembly was still seen as a reward. The students evidently enjoyed sharing their learning and achievements with the whole school.

The ratio of adults to students was one to six, which facilitated using scripted questions to scaffold student talk. Student–student talk can be made more effective using strict protocols, such as groupings that assign roles to the students (Hennah, 2018c). Structuring how students talk together becomes vital when the teacher–student ratio rises to 1 to 30.

Open badges: conclusions

Having successfully conducted prior studies into using digital badges within the secondary sector, a primary school was selected for this study. Working with an unfamiliar age group allowed the author to ascertain whether or not the language and methods suggested would be appropriate for younger children. The trial, within its limits, was encouraging, as the students were seen to engage with the learning in an informal setting.

Recordings made of students following this instruction strategy revealed that they were able to:

- select appropriate equipment for an investigation;
- use and recall best practice techniques with measuring equipment;
- plan a strategy for collecting data to address a question;
- correctly use targeted scientific vocabulary.

This trial suggests that the open badge 'Working Scientifically' framework (Hennah, 2018b) could provide a mechanism that encourages structured talk and the development of practical competencies by rewarding the steps along a learning trajectory.

Table 1 maps out the range of apparatus and techniques that are met in schools, many of which are met again at later stages. This trial was concerned with developing basic procedures and manipulations concerning measurement, the foundations required for progress through the manipulative skill hierarchy (Fadzil and Saat, 2017). Johnstone (2006) concluded that the failure of laboratory work to connect with the underlying theory is due to the load imposed upon working memory, which leaves no room for cognitive processing. For example, psychomotor skills (hands-on) and cognitive ability (minds-on) must be integrated when performing practical tasks in order to be competent at manipulating certain apparatus. If such schema are stored in the long-term memory ready for retrieval then less load is imposed on the working memory. With consistent focus on developing these skills throughout school science, students may be afforded a better opportunity to think about the underlying concepts during practical work:

> *It is essential so to establish the manipulative skills that they can 'go on auto-pilot' and free the student's attention for other things such as observation and accurate recording.* (Johnstone and Al-Shuaili, 2001: 43)

Summarising Open badges Parts 1 to 3

The impact of being able to recognise and name skills employed in different contexts cannot be overemphasised. Young people are faced with life-changing decisions that they frequently feel too ill informed to make: What subjects should I choose? What course should I do? What do I enjoy? What can I do? Lacking in self-awareness they rely more heavily on other people's opinions, rather than trusting their own judgement. Recognising and assessing learning that takes place across different contexts allows learners to reflect on the development of their own skills and interests. By developing this self-awareness learners are more able to make informed choices, identify their strengths and become self-regulated learners (Zimmerman, 2002), empowered to actively seek to develop skills they value or even enhance those skills they deem important but feel they lack.

Throughout this series particular attention has drawn to the benefits of scientific literacy and practical skills mastery as tools for reducing cognitive load to ameliorate thinking and learning. The second article (Hennah, 2018b) offered a detailed open badge framework for the 'Working Scientifically' strand of the science curriculum. Within this framework, guidance was given as to when to introduce new vocabulary, problematic terms to be aware of, and talk strategies that focus on dialogue. The digital nature of these badges facilitates talk and practical skills because they may be evidenced through digital recordings. Placing a greater emphasis on talk during practical work presents the working memory with both auditory (verbal) and visual (non-verbal) information, which Dual Coding Theory (Sadoski, McTigue and Paivio, 2012) attests reduces the potential for cognitive overload and supports memory retrieval.

The proposed open badge framework for the 'Working Scientifically' strand of the science National Curriculum in England, described in this work, is well aligned with the Education Endowment Foundation recommendations for improving secondary science (EEF, 2018). Throughout the series attention has been drawn to the theories that underpin the strategies recommended so teachers can incorporate the methods and practices into their own lessons. Beck and McKeown (1984) explain that providing evidence to support teaching recommendations allows teachers to modify recommendations to fit the needs of their classrooms and students while maintaining the underlying foundation. The strategies that have been described here seek to benefit students regardless of their age throughout their science education.

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Research-informed adaptations to school practical work

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Why do we do practical work?

Practical work describes whole class hands-on laboratory tasks during which students, manipulate materials, make observations, and reproduce phenomena (Abrahams & Millar, 2008). Many teachers of chemistry value hands-on practical work as a means of engaging students and making chemistry come alive.
"Chemistry is necessarily an experimental science; its conclusions are drawn from data, and its principles supported by evidence derived from facts" (Faraday, 1827 p.b).

In England, the exam boards set out the apparatus that students should use and the techniques they should develop. The students' practical skills are assessed in the terminal exams, which contain questions that specifically draw on the experience students have gained from doing practical tasks. Schools are encouraged to include "purposeful practical activities" as part of the day-to-day teaching and learning. Purposeful practical activities are defined as those in which the teachers know the purpose of the activity, *"and it should be planned and executed so it is effective and integrated with other science learning"* (Gatsby, 2017, p. 45). The Assessment and Qualification Alliance (AQA) exam board states that by *"focusing on the reasons for carrying out a particular practical, teachers will help their students understand the subject better, to develop the skills of a scientist and to master the manipulative skills required for further study or jobs in STEM subjects" (*2019, p101).

Working memory and practical work

Human cognitive architecture is made up of the long-term memory, which can store very large amounts of information, and the working memory, which is limited by both its capacity and its duration. Indeed, the working memory has been described as 'the limited mental "space" in which we think' (Clark, Kirschner, & Sweller, 2012, p. 8), and is roughly equivalent to what humans are conscious of at any one time. Cognitive load is the term used to describe the demand placed on the working memory by a task; when the load becomes too high, learning is impaired (for a comprehensive and open access overview see Sweller, van Merriënboer, & Paas, 2019).

School practical work has been described as "cookbook" or "recipe following" (Clackson, & Wright, 1992) with task completion at the forefront of students' minds. If practical work is to meet the expectations previously described, then the learners must have both hands-on and minds-on (Abrahams, & Millar 2008). This disconnect between objectives and outcomes has been attributed to the learner's working memory becoming overloaded by the task, which leaves little or no space for thinking beyond immediate actions (Johnstone & Wham, 1982).

Pre-laboratory preparation

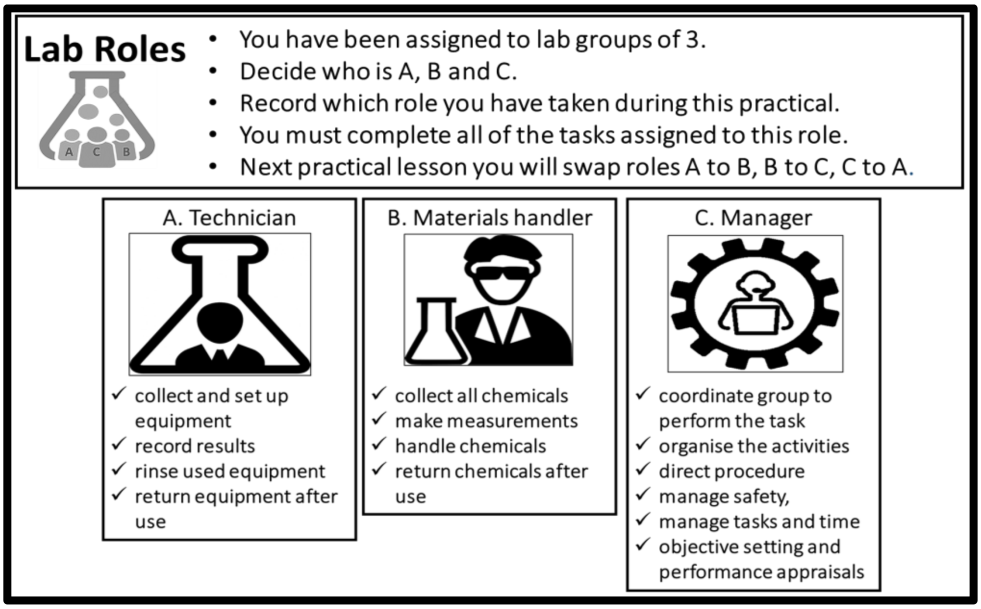
Pre-laboratory preparation refers to the practice of providing learners with an activity to complete that builds familiarity with the conceptual procedural knowledge required by a practical task. Before our students undertake a practical task detailed by the exam specification, they are asked to watch a video or simulation about the task as homework. This is done to try to reduce the amount of new information students are being exposed to in the laboratory. Introducing students to the equipment and lab protocol aims to remove some of the cognitive load imposed by performing the experiment. We have found that practical lessons are more efficient when the students come preprepared, which is vital as limited teaching time prevents repeated attempts to complete the same task. (See Hennah, 2019).

Collaboration and practical work

Researchers have found that laboratory work can function as an active learning environment if students are provided with time to talk and discuss what they are doing (Lunetta, Hofstein, & Clough, 2007). Language is a communicative tool used by and between people to make meaning, Vygotsky's sociocultural theory understands that knowledge is not transmitted from one individual to another but co-constructed through social interaction (Vygotsky, 1978). When working together, students not only interact, they 'interthink' (Littleton & Mercer, 2013). The use of language and other modes of representation enable learners to link their individual minds to create a more powerful information-processing system, which Mercer (2013) describes as the "social brain". Collaborative learning can be defined as a learning situation during which students actively contribute to the attainment of a mutual learning goal and try to share the effort to reach this goal. According to Cognitive Load Theory, learners in collaborative groups are considered as a single information-processing system, as the processing is divided across individuals (Eilks *et al*. 2009). Hands–on practical tasks afford students with the opportunity to interact with each other as well as the procedures and materials of science. Transforming group work into collaborative learning requires the class materials to be modified so that every member of the group is responsible for contributing to the group work and the group's success.

Lab Roles

To support the development of collaboration in our lessons, students are organised into groups of three which are maintained for all practical activities. The groups, like seating plans, are decided by the teacher and are maintained throughout the year so the class becomes accustomed to this style of working. Prior experience of collaborating as a team has been shown to increase efficiency and performance. Grouping students as trios rather than pairs reduces issues caused by a group member being absent, whilst still being a small enough grouping for everyone to be engaged. The roles in Figure 1 below, delineate the contributions each member is expected to make (Gaunt & Stott, 2018). The three lab roles are rotated within a group every practical lesson, so that every student experiences each role a number of times.



Lab Roles

- You have been assigned to lab groups of 3.
- Decide who is A, B and C.
- Record which role you have taken during this practical.
- You must complete all of the tasks assigned to this role.
- Next practical lesson you will swap roles A to B, B to C, C to A.

A. Technician

- ✓ collect and set up equipment
- ✓ record results
- ✓ rinse used equipment
- ✓ return equipment after use

B. Materials handler

- ✓ collect all chemicals
- ✓ make measurements
- ✓ handle chemicals
- ✓ return chemicals after use

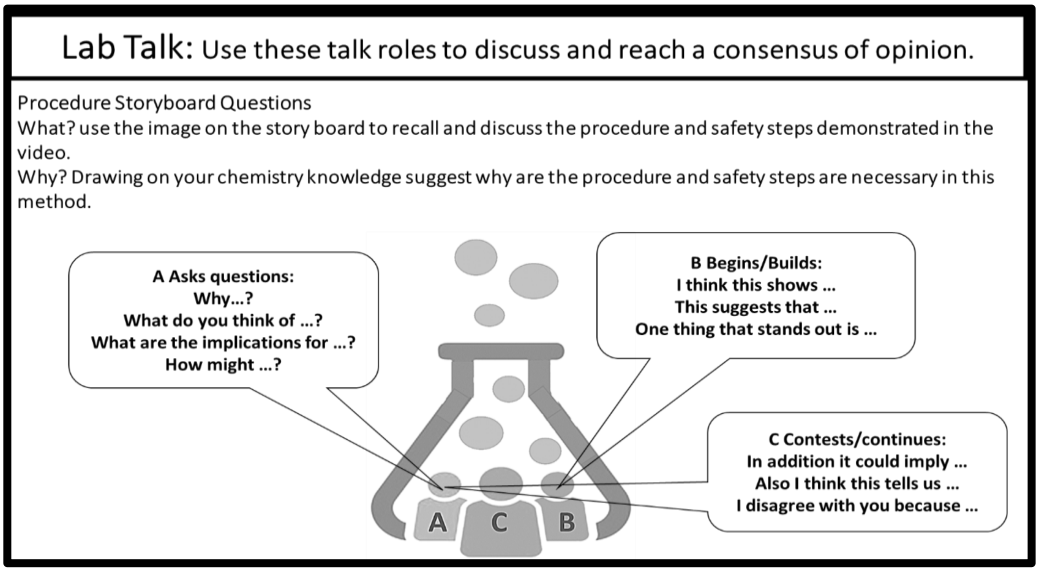
C. Manager

- ✓ coordinate group to perform the task
- ✓ organise the activities
- ✓ direct procedure
- ✓ manage safety,
- ✓ manage tasks and time
- ✓ objective setting and performance appraisals

Figure 1: Lab Roles derived from the work of Ott *et al.* (2018) (Hennah, Newton and Seery, 2022)

Lab Talk

Evidence-based arguments form the basis by which scientific knowledge is used, tested and revised. The importance of argumentation in chemistry education, including in laboratory learning, is well documented (see Erduran, 2019). However, students need structures to support the development of their discussion and argumentation skills (Gaunt & Stott, 2018). We have introduced Lab Talk (Figure 2) alongside Lab Roles to provide this support and encourage discussion during practical work. We seek to provide students with time and opportunity to construct arguments such as: *evaluating data in terms of accuracy, and precision; identifying potential sources of random and systematic error; presenting reasoned explanations relating data to hypotheses; and drawing conclusions. Our goal is to develop discussion, so it is integral to the practical task and in this way create a hands-on and minds-on environment.*



Lab Talk: Use these talk roles to discuss and reach a consensus of opinion.

Procedure Storyboard Questions
What? use the image on the story board to recall and discuss the procedure and safety steps demonstrated in the video.
Why? Drawing on your chemistry knowledge suggest why are the procedure and safety steps are necessary in this method.

A Asks questions:
Why...?
What do you think of ...?
What are the implications for ...?
How might ...?

B Begins/Builds:
I think this shows ...
This suggests that ...
One thing that stands out is ...

C Contests/continues:
In addition it could imply ...
Also I think this tells us ...
I disagree with you because ...

Figure 2: Lab Talk derived from the work of Gaunt, & Stott (2018) (Hennah, Newton and Seery, 2022)

A practical skills curriculum?

The adaptations suggested here support the classroom practitioner in improving the conditions for learning during practical tasks. Pre-laboratory preparation homework activities extend the time spent on practical work without taking up more teaching time. When students have prior knowledge of the task, the cognitive load imposed on the working memory by verbal and written instructions containing unfamiliar vocabulary, equipment and techniques is reduced, leaving more space for thinking. Training students to carryout hands-on tasks using Lab Talk and Lab Roles will facilitate collaborative learning once the approaches are established.

Encouraging students to talk and reason during the task builds familiarity with scientific language and culture but only if students are competent in science manipulative skills (Johnstone & Al-Shuaili, 2001). It is likely that the combination of a curriculum designed to develop scientific language, process competencies, and manipulative skills throughout compulsory education (see for example Hennah, 2018), as well as developing classroom practice as discussed here, would greatly improve school practical work.

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□

Biography

Naomi Hennah has been teaching school chemistry/science for nearly twenty years. Her classroom research is focused on oracy as a tool to build both familiarity and understanding of the language of chemistry. Since joining Northampton School for Boys in 2014, Naomi has completed a Master's degree in Education (Applied Linguistics) and was the Royal Society of Chemistry Schools Education Award winner for 2018.

Northampton School for Boys

Developing Oracy Skills:

a method to improve comprehension and acquisition of the language of chemistry

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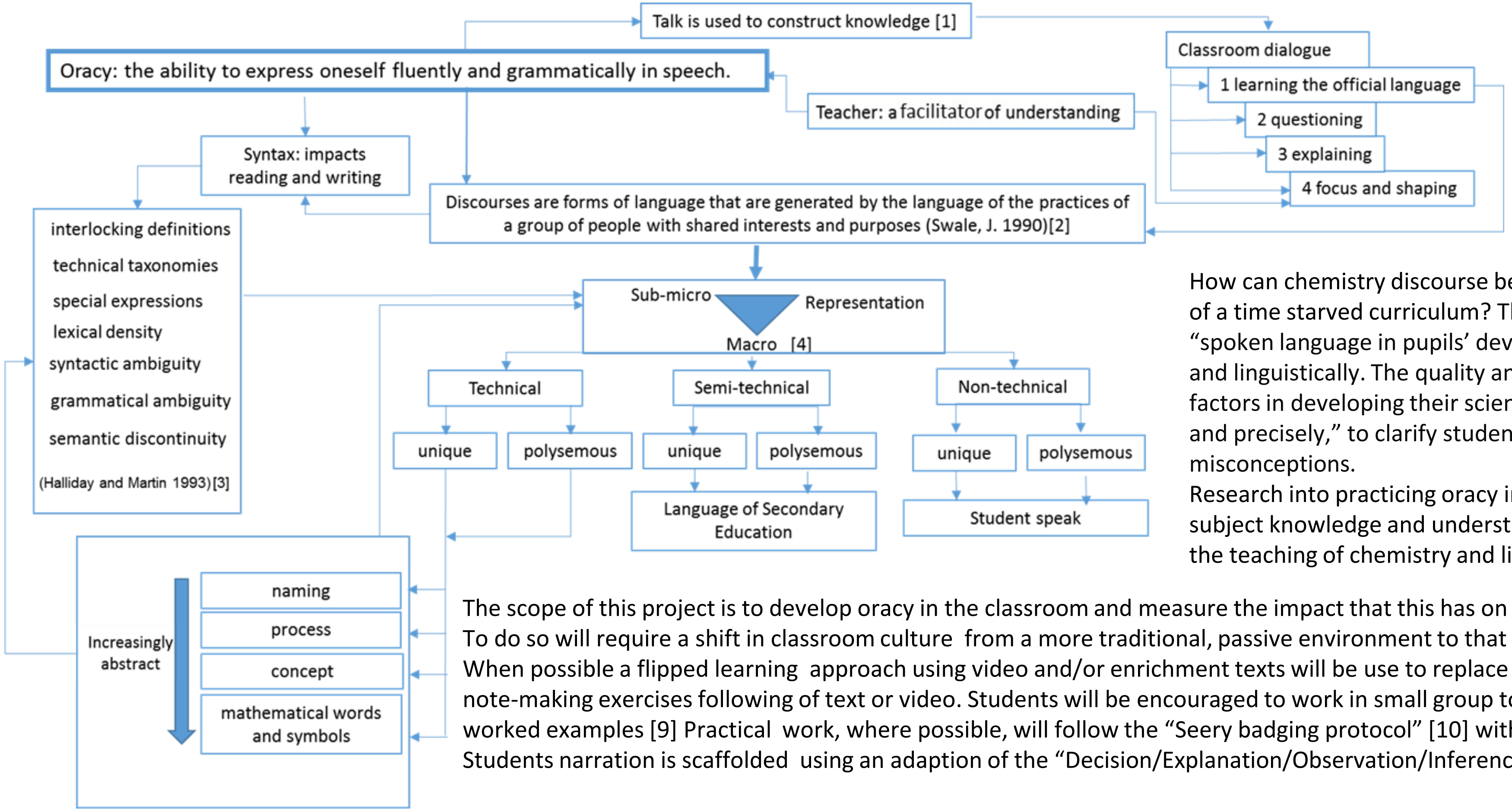
Teachers are required to facilitate understanding, nurture transferable skills, present the syllabus content, show progression and prepare learners for exam success; to do so requires words. Thus the teaching of chemistry must encompass the development of linguistic skills. Words are at the heart of knowledge and understanding, but it is unwise to assume we share their meaning; *"the difficulty lies more with the grammar than the vocabulary ……the problems with the technical terminology usually arise not from the terms themselves, but from the complex relationships they have with each other. " Halliday, 1993*

Taber (2015) discusses the complexity of the language used in chemistry, its many facets and the barriers they present to understanding. Drawing on these ideas and those of other authors [5], I have created a visual summary of the complexity of chemical discourse.



Talk is used to construct knowledge [1]

Oracy: the ability to express oneself fluently and grammatically in speech.

Teacher: a facilitator of understanding

Classroom dialogue

1 learning the official language

2 questioning

3 explaining

4 focus and shaping

Syntax: impacts reading and writing

Discourses are forms of language that are generated by the language of the practices of a group of people with shared interests and purposes (Swale, J. 1990)[2]

interlocking definitions

technical taxonomies

special expressions

lexical density

syntactic ambiguity

grammatical ambiguity

semantic discontinuity

(Halliday and Martin 1993)[3]

Sub-micro

Representation

Macro [4]

Technical

unique

polysemous

Semi-technical

unique

polysemous

Language of Secondary Education

Non-technical

unique

polysemous

Student speak

Increasingly abstract

naming

process

concept

mathematical words and symbols

Overt teaching of technical terms and semi-technical terms, such as command words through the use of; word banks, matching exercises like Polysemy Pairs or loop games and concept cards, all provide opportunities to meet and define new vocabulary. Socratic Questioning Technique using chemical misconceptions as the stimulus work's is an effective method for uncovering ideas and rehearsing vocabulary [6].

How can chemistry discourse be better presented, rehearsed and used within the confines of a time starved curriculum? The national curriculum for science [7] refers to the need for "spoken language in pupils' development across the whole curriculum – cognitively, socially and linguistically. The quality and variety of language that pupils hear and speak are key factors in developing their scientific vocabulary and articulating scientific concepts clearly and precisely," to clarify students' thinking and use discussion to probe and remedy their misconceptions.

Research into practicing oracy in classrooms has been shown to aid the development of subject knowledge and understanding [8]; however, most of this work is based outside of the teaching of chemistry and limited to primary school science.

The scope of this project is to develop oracy in the classroom and measure the impact that this has on technical and semi-technical language acquisition.

To do so will require a shift in classroom culture from a more traditional, passive environment to that of active collaborative enquiry.

When possible a flipped learning approach using video and/or enrichment texts will be use to replace note-taking with small group discussion and scaffolded note-making exercises following of text or video. Students will be encouraged to work in small group to tackle exam style questions supported by a framework of worked examples [9] Practical work, where possible, will follow the "Seery badging protocol" [10] with an increased emphasis on narrating actions during filming.

Students narration is scaffolded using an adaption of the "Decision/Explanation/Observation/Inference" writing method [11]

Developing Oracy Skills:
a method to improve comprehension and acquisition of the language of chemistry

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Discussion questions

(Discuss via Twitter – remember to use #MICER17 – or in the comments below)

- Are multiple choice questions an effective tool for determining language comprehension?
- How can the link between oracy development and language comprehension be effectively determined?

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Naomi
Hennah

Sophie
Newton

Linking Procedures and Concepts in GCSE Chemistry
One Video Two Voice-Overs

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All the information contained in instructional material must be processed by working memory, design of instructions and learning opportunities must consider cognitive load to make space for linking ideas (de Jong, .2010). Practical work is considered as a tool to help students link the domain of observables to the domain of ideas (Millar and Abrahams 2009), however, task demands can overwhelm working memory forcing students to use written instructions as a “minds-neutral” recipe (Johnstone, 2006). Working memory has two processing systems that initially process visual and verbal information independently. Thus, information presented in more than one modality is divided across two of these systems, effectively reducing the cognitive load applied. (Kirschner,2002).

What if we use a practical video to link the two domains, a procedure voice-over representing the domain of observables and a concept voice-over representing the domain of ideas linked by the same visual images?

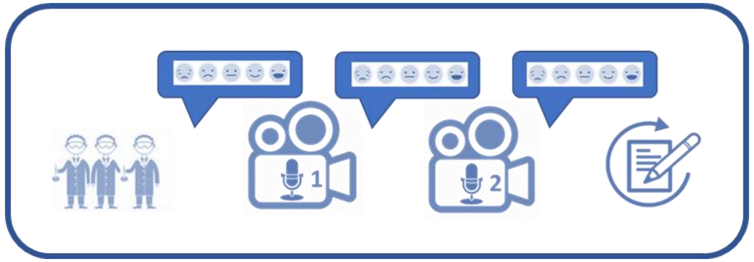
Image Key

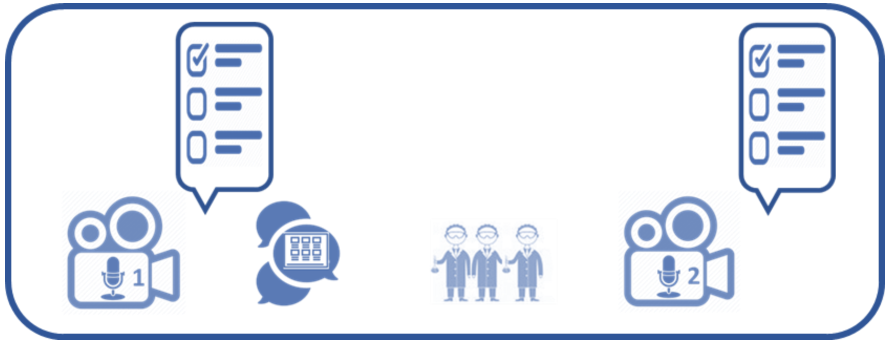
- procedure voice-over video
- concept voice-over video
- practical activity
- storyboard method construction
- Likert-scale affective questionnaire
- two-part multiple choice
- revision

Does making links between exemplar videos showing either practical procedure or underlying concepts increase learners' confidence in their understanding of GCSE core practical tasks?

Using practical videos with two voice-overs to prepare for laboratory work and to reinforce underlying concepts afterwards. Affective data reports an increased in student confidence in understanding both practical procedure and the underlying concepts.

Using practical videos with two voice-overs as a revision resource for terminal assessment to recall and reinforce procedures and underlying concepts in practical work that had been conducted in the previous school year. Affective data reports an increased in student confidence in understanding both practical procedure and the underlying concepts.





In earlier work using a novel pedagogy; pre-laboratory preparation video and method construction using a talking point prompt, students demonstrated greater a retention of the procedure as compared to when they had followed a traditional pedagogy.

Can grater retention be achieved by further developing the dialogic- teaching approach (Ruthven et al. 2017)? Structuring oracy: Students work in talk triads with a storyboard to construct the method before undertaking the practical work. Collecting data: two-part multiple choice quizzes (choose the correct response and briefly explain your reasoning) to identify patterns in responses from test groups and controls .

This work is supported by the RSC CERG teacher-researcher scheme.

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Dialogic-Teaching Approach to Practical Work

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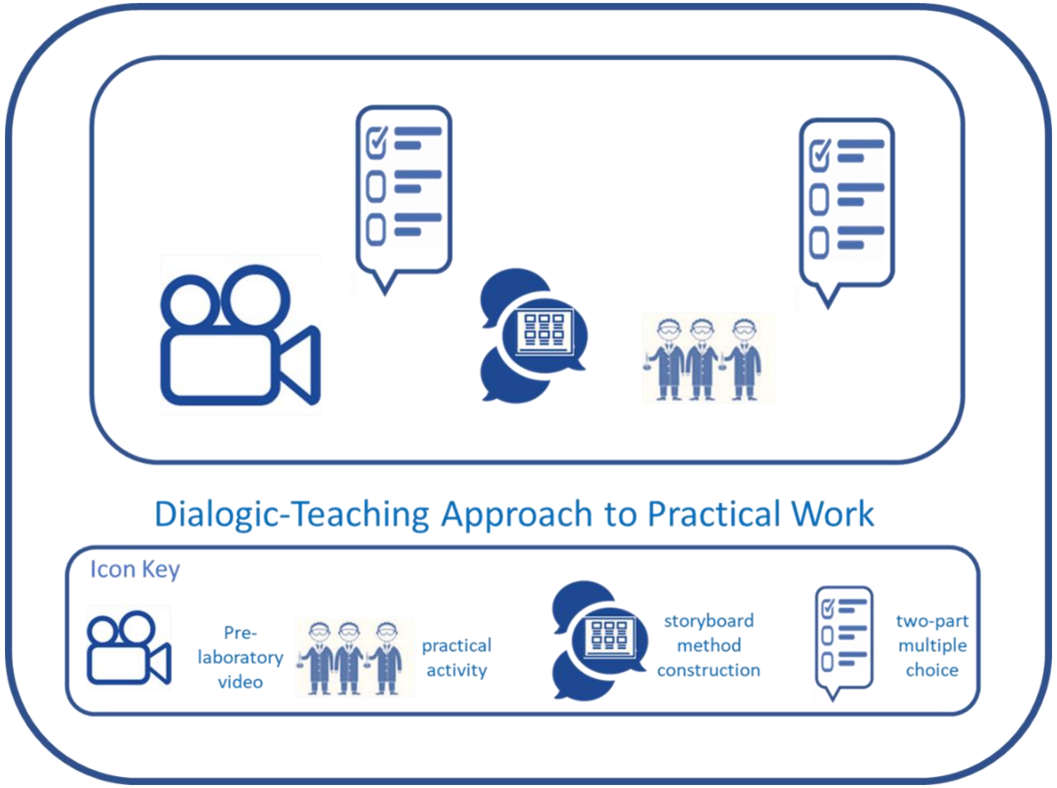
TALK
Chemistry

nsb

A novel pedagogy for terminal assessment of GCSE comprised of a pre-laboratory preparation video and method construction through talk, demonstrated a statistically significant increase in practical procedure retention compared to following a traditional pedagogy (Hennah 2018). This work seeks to further develop the dialogic- teaching approach (Ruthven et al. 2017) to practical laboratory work to support students’ understanding of both practical procedures and their underpinning concepts. Having watched a pre-laboratory video, students work in talk triads with a storyboard to construct the method before undertaking the practical work. Two-part multiple-choice quizzes (choose the correct response and briefly explain your reasoning) will be used to identify patterns in responses from the test group sand control groups.



Dialogic-Teaching Approach to Practical Work

Icon Key

- Pre-laboratory video
- practical activity
- storyboard method construction
- two-part multiple choice

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Education Research Fellowship Scheme 2018

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Using Oracy to Reduce Cognitive Load in the Laboratory

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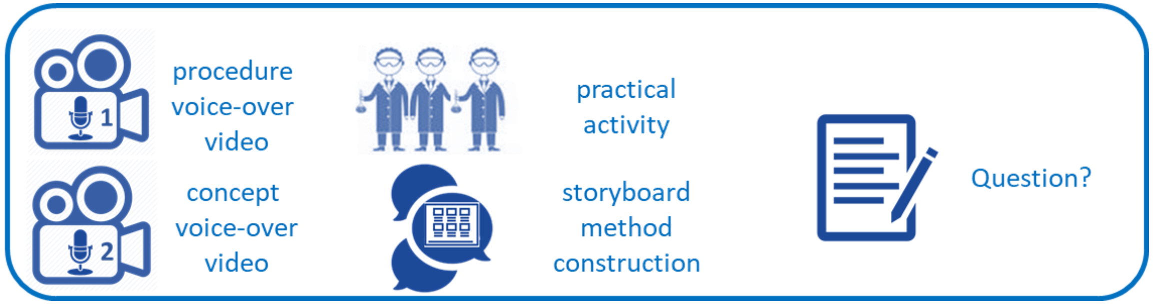
Education Research Fellowship Scheme 2018

One Video Two Voice Over and Oracy Protocol



procedure voice-over video

concept voice-over video

practical activity

storyboard method construction

Question?

Next Steps: Testing the Protocol

2 GCSE Required Practical activities with one video two voice over tailor made videos and tests.

3 GCSE chemistry groups:
1 worksheets no video;
2 worksheets and video;
3 story board and video.

Research Questions:

Does the use of these videos impact attainment on these tests?

Does the story board method oracy activity impact attainment on these tests?

In earlier work using one video with two voice overs student reported an increased confidence in procedural and conceptual knowledge associated with the practical task. Preliminary tests showed an increase in attainment in tests, correct responses to procedural knowledge questions increased after the first video and correct responses to conceptual knowledge questions increased after the second video. Using the pre-laboratory procedure voice-over video enabled students working in triplets to use a video storyboard to construct a suitable, safe method to follow during the practical task.

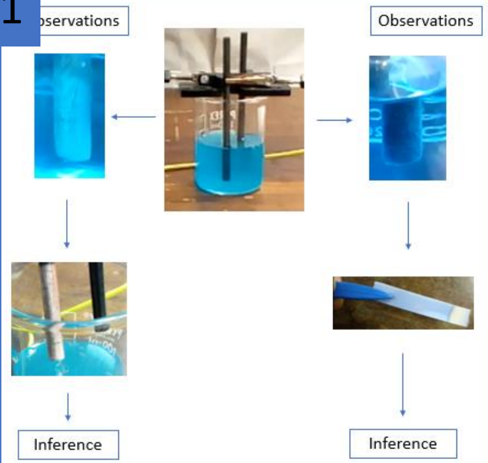
Designing a diagnostic test: Students had difficulty answering multiple choice questions; feeling confused and choosing more than one answer. A two-tier multiple choice question format was then adopted that used less confusing questions however, the reasoning sections were predominately left blank. A third strategy using short response exam style questions was preferred by the students and although more time consuming to mark has been adopted.

TARGET TALK by Naomi Hennah @MrsHennah

Northampton School for Boys

To what extent can oracy plenaries support students' understanding of chemistry's three levels of representation?

1



Talking Point: Electrolysis of copper(II) chloride solution

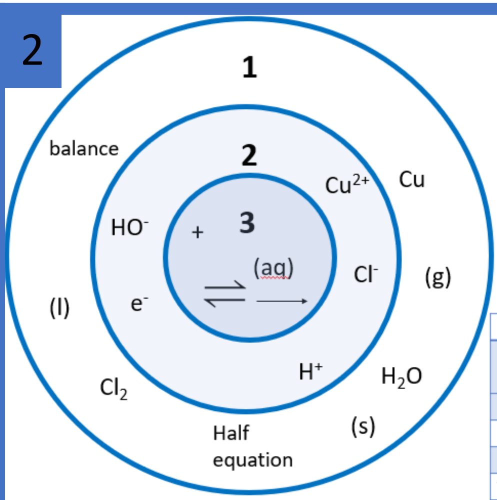
Images from a practical activity are used to encourage students to reconstruct their observations and inference.

Purpose: Talk to generate ideas, analyse and evaluate, come to a consensus.

Groups of 3:
Take turns and manage interactions.
Build on and challenge each other's ideas.
To reach a consensus.

*Talking points were developed by Lyn Dawe

2



Summary Bullseye

Purpose: Talk to understand, acquire new vocabulary, analyse and evaluate

In this activity students are challenged to summarise a process using target vocabulary.

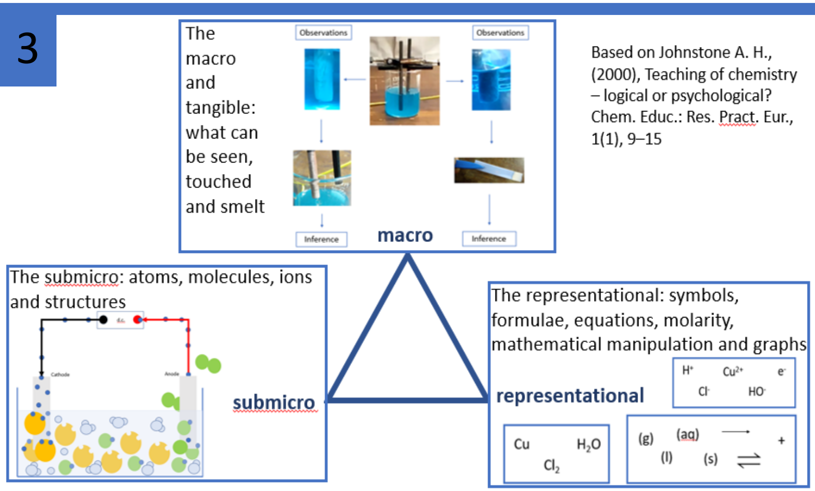
outcomes:

- Enables students to use new vocabulary
- Scaffolds focused trio-group listening
- Enables students to prioritise and organise information

Score Tally Table

point	Names		
1			
2			
3			
Total			

3



The macro and tangible: what can be seen, touched and smelt

macro

The submicro: atoms, molecules, ions and structures

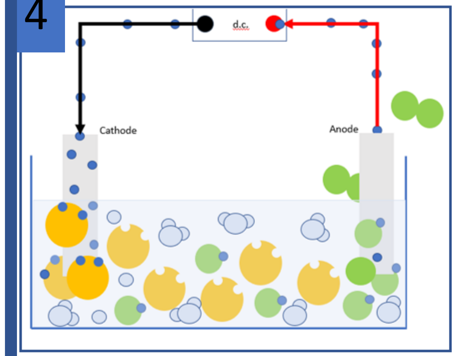
submicro

The representational: symbols, formulae, equations, molarity, mathematical manipulation and graphs

representational

Based on Johnstone A. H., (2000), Teaching of chemistry – logical or psychological? Chem. Educ.: Res. Pract. Eur., 1(1), 9–15

4



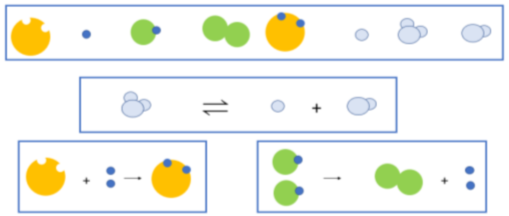
Talking Point: Explaining electrolysis of copper chloride solution

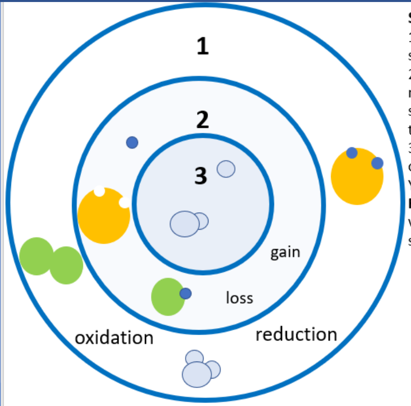
Say what you see.

Purpose: Talk to generate ideas, analyse and evaluate, come to a consensus.

Groups of 3:
Take turns and manage interactions.
Build on and challenge each other's ideas.
To reach a consensus.

Talking point prompts: use these to help you explain what the talking point shows





Summary Bullseye

1. Students work in threes; one speaker, one scorer, and one recorder.
2. Speaker starts, giving their summary using as much of the vocabulary as they can, while the scorer identifies points and the recorder keeps the tally. The students then switch roles.
3. Students discuss their ideas and seek agreement on the best way to arrange the summary.

You may be asked to share this with the class.

Rules: Points can be deducted for incorrect use of vocabulary, using fillers, failing to link ideas or sequence the information correctly

Score Tally Table

point	Names		
1			
2			
3			
Total			

Talking point prompts: use these to help you explain what the talking point shows

electrolyte	graphite	molecule	inference	wire
anode	electrode	electron	gain	positive
cathode	electrolysis	aqueous solution	loss	negative
inert	atom	external circuit	move toward	blue litmus
half equation	ion	ionic equation	attract	bleach
oxidation	reduction	observation	terminal	copper(II) chloride

Dialogic pedagogy offers the opportunity for students to use talk to think together (Mercer, N. 1995). Effective small group activities allow students to reason together and develop their metacognition but require clear protocols and well structured activities (Ruthven et al. 2017) such as theses oracy tools*,Talking Point (Image 1) and Summary Bullseye (Image 2).

Chemistry is communicated by three levels of representation (Johnstone 2010, Taber 2013). Image 3 illustrates how the electrolysis of copper(II) sulfate may be viewed from each level. Each apex of the triangle and their interconnectedness are essential for achieving a conceptual understanding of chemical phenomena (Thomas, 2017). Image 4 provides an example of the submicroscopic level, using the Talking Point, students seek a consensus explanation of the image. Additional scaffolding may be provided by Talking Point prompts and teacher intervention. Summary Bullseye, formative assessment, is used in the following lesson to test individuals' ability to summarise, sequence and apply their knowledge of the talking point. Each apex is individually considered prior to a terminal task that requires students to operate between the different levels.

Target talk seeks to make the different levels of representation and how they are connected more familiar to students by providing the opportunity to explore their own understanding and to explicitly practice using these representation.

*Oracy tools https://www.voice21.org/ and https://www.educ.cam.ac.uk/research/projects/oracytoolkit

References: Johnstone A. H., (2010), You can't get there from here, J. Chem. Educ., 87(1), 22–29.
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Oracy Leaders Programme:

Impact Project “Practical Talk” Overview

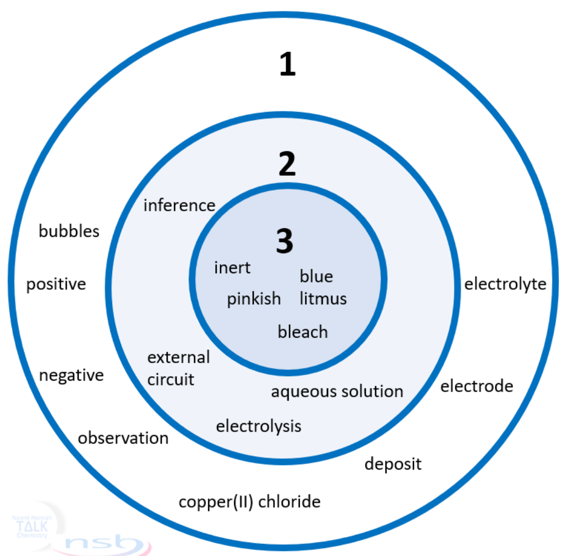
Name: Naomi Hennah

School: Northampton School *for* Boys

The Focus

Can talk protocols be developed and implemented in GCSE chemistry lessons to support students’ knowledge and understanding of a required practical task, the electrolysis of copper chloride solution? Implementing Lyn Dawes’ Talking Points and Voice21’s Bullseye as plenary activities in GCSE chemistry.

The Strategies



Macroscopic Bullseye

Person A begins to explain the electrolysis of copper chloride aiming to correctly use as many of the words in the target as they can. Person C uses the tally chart to keep the score. Then person B builds on from A and tries to reach a higher score than A. Person C continues to keep the score and declares a winner

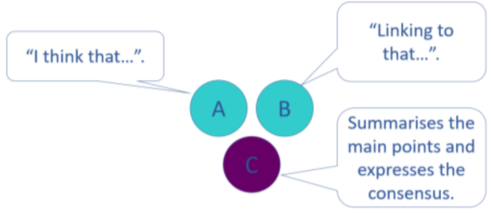
Rules: Points can be deducted for incorrect use of vocabulary, using fillers, failing to link ideas or sequence the information correctly.

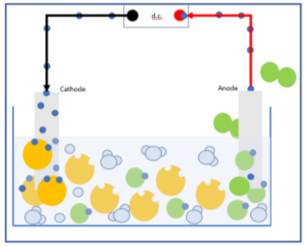
Score Tally Table

point	Names		
1			
2			
3			
Total			

Talking Point Roles

Person A begins the discussion Person B builds on from A, …” Lastly person C “The main points were…”





Sub-Microscopic Talking Point: identify the particles and describe what is happening during the electrolysis of copper(II) chloride solution
Say what you see.

The Next Steps

I hope to continue developing and refining resources and sharing ideas to support teachers and students in learning chemistry. Initially I would like to continue to develop activities to support the 8 chemistry required practical tasks. These ideas may be expanded into other areas of science and maths. I hope to help raise the profile of oracy in science education. I would like to work with colleagues from other subjects to share good practice and further embed oracy in the school and area.

The Results

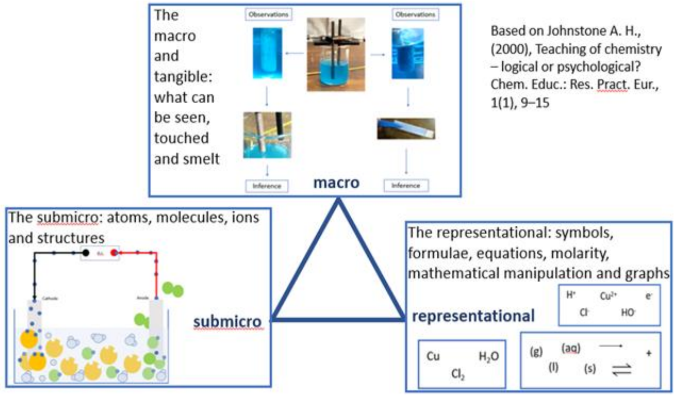
Students are becoming more proficient in using the materials which should continue to improve as common oracy strategies are more widely utilised around school.. Oracy strategies are attracting interest in the chemistry community as early data collected indicates that these methods support students retention of practical procedures. Anecdotal evidence indicates that explicit teaching of the three levels of representation supports understanding of chemical concepts.

Chemistry can be represented on three levels:

1.The macroscopic which includes the phenomena we can see and touch.

2.The sub-microscopic, these are the particles and how they are arranged and rearranged to produce the phenomena we can see and touch.

3.The symbolic level that includes the formulae and equations with which we represent chemical phenomena.


The macro and tangible: what can be seen, touched and smelt

The submicro: atoms, molecules, ions and structures

The representational: symbols, formulae, equations, molarity, mathematical manipulation and graphs

Based on Johnstone A. H., (2000), Teaching of chemistry – logical or psychological? Chem. Educ.: Res. Pract. Eur., 1(1), 9–15

“Like Milk in Cola.”

Using Spoken Language to Facilitate the Transition from Novice to Master

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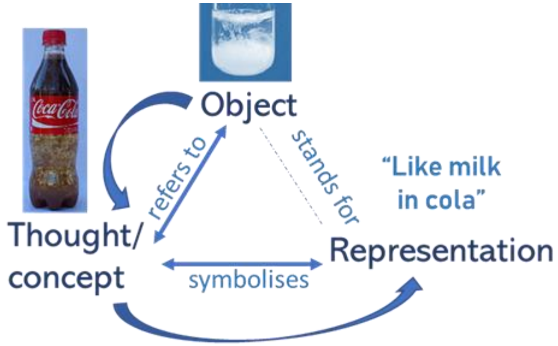
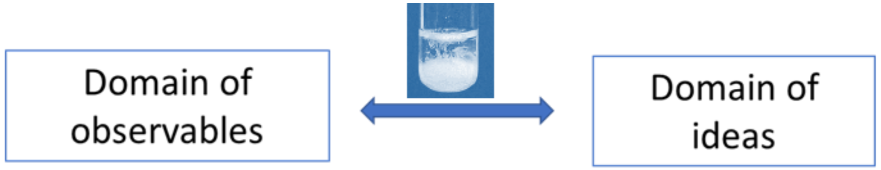
1



Semiotic triangle adapted from Ogden & Richards 1923

It is language that differentiates between a white precipitate and milk in cola. Language manifests and structures thought. Speech shapes the higher mental processes needed for learning in formal education.

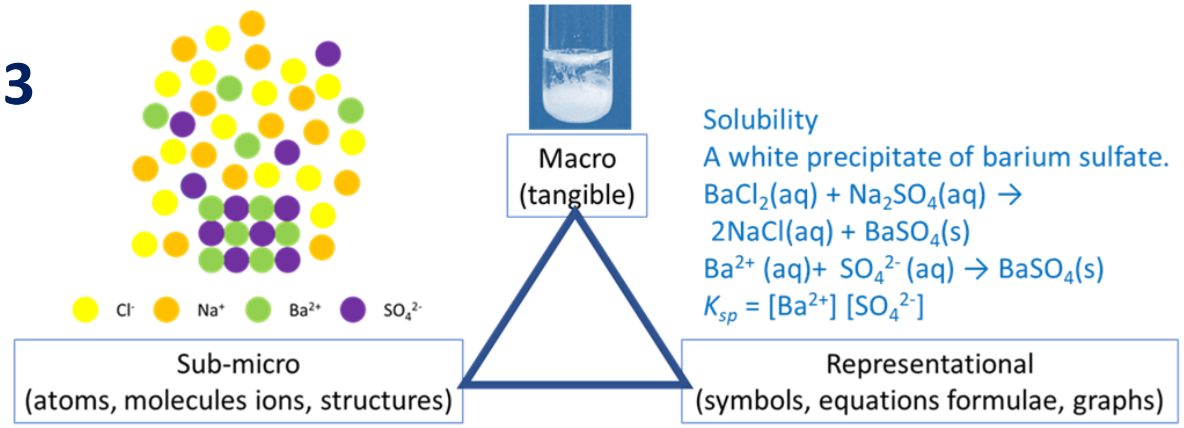
2



Practical work linking two domains (Tiberghien 2000)

Cognitively demanding talk supports learning and provides learners with the language repertoire necessary to express what they do and do not understand, which empowers teachers to make better informed pedagogical decisions and expedite learning.

3

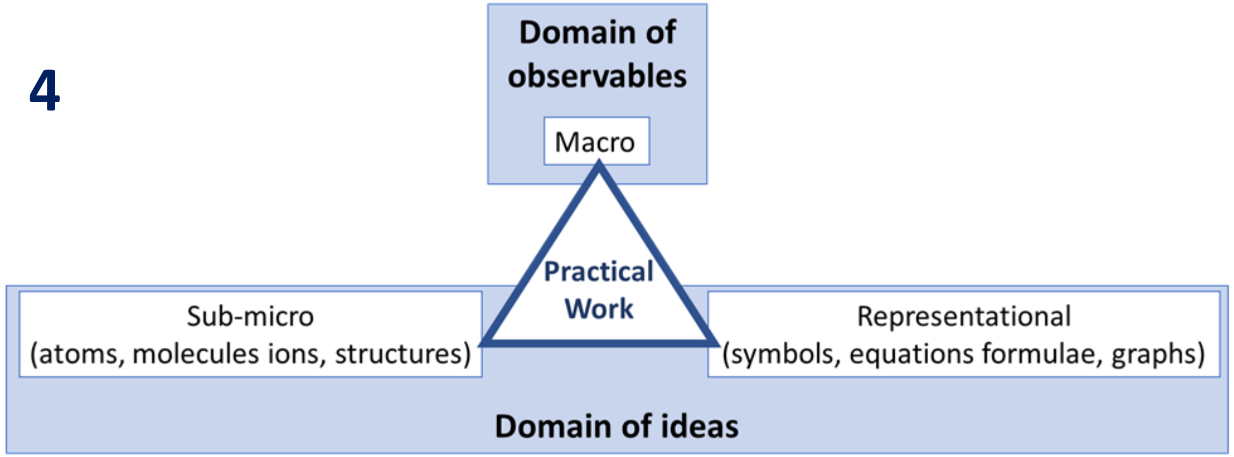


Solubility
A white precipitate of barium sulfate.
$BaCl_2(aq) + Na_2SO_4(aq) \rightarrow$
$2NaCl(aq) + BaSO_4(s)$
$Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s)$
$K_{sp} = [Ba^{2+}][SO_4^{2-}]$

The three conceptual domains of chemistry known (Johnstone 2006)

Experts cannot assume that the three levels of representation exist in the novice mind. Provide opportunities for learners to discuss practical activities from each apex of Johnstone’s triangle and, with practice, interpersonal interaction will be transformed into intrapersonal cognitive habit.

4



Talk mediates the cognitive and cultural space between the expert and the novice; teachers must engineer interactive opportunities that facilitate such mediation.

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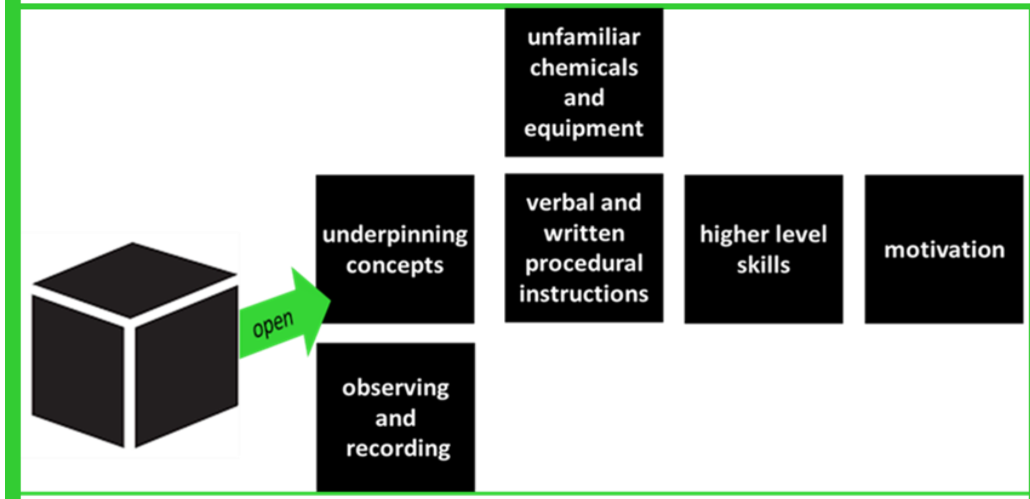
Practical Task Demand: Opening The Black Box To Facilitate Learning

1 The purpose of practical work has received much attention[1] however, literature regarding the task demand of these activities is less evident despite demands for “minds-on” and “hands-on”[2] activities. Task demands compared to the resources available for performing the task determines an activities cognitive load[3], practical tasks place so many demands on a student’s working memory that little space remains for cognitive processing[4]. Pre-laboratory tasks such a watching a techniques video[5], provide a mechanism for increasing the resources available to the learner lessening the load imposed, here we investigate whether providing an alternative voice over to the same video detailing the underling chemical concepts could further facilitate learning. Furthermore, practical tasks are complex tasks[6] (Figure 1) in which effective collaboration can provide a scaffold for learning[7], in accordance to which we have introduced students to adopting defined laboratory task and talk roles (Figure 2).



unfamiliar chemicals and equipment

underpinning concepts

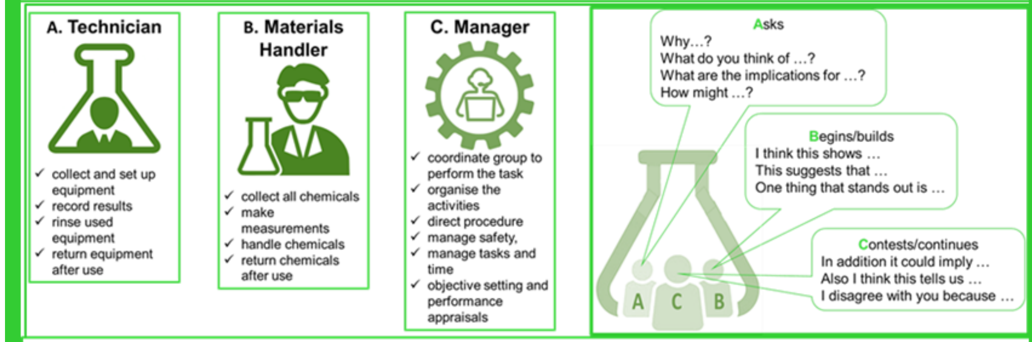
verbal and written procedural instructions

higher level skills

motivation

observing and recording

Figure 1 Practical task demand, practical tasks are complex tasks in which the a number of elements interact to increase intrinsic load[7]



A. Technician
- ✓ collect and set up equipment
- ✓ record results
- ✓ rinse used equipment
- ✓ return equipment after use

B. Materials Handler
- ✓ collect all chemicals
- ✓ make measurements
- ✓ handle chemicals
- ✓ return chemicals after use

C. Manager
- ✓ coordinate group to perform the task
- ✓ organise the activities
- ✓ direct procedure
- ✓ manage safety,
- ✓ manage tasks and time
- ✓ objective setting and performance appraisals

Asks
Why…?
What do you think of …?
What are the implications for …?
How might …?

Begins/builds
I think this shows …
This suggests that …
One thing that stands out is …

Contests/continues
In addition it could imply …
Also I think this tells us …
I disagree with you because …

Figure 2 Laboratory Task and Talk Roles

References 1.Cukurova, M., Hanley, P. and Lewis, A., (2017). 2.Abrahams, I. and Reiss, M.J., (2012). 3. Reif, F., (2008). 4. Johnstone, A.H., (2006) .5. Agustian, H.Y. and Seery, M.K., (2017). 6. Van Merriënboer, J.J. and Kirschner, P.A., (2017). 7 Kirschner, P.A., Sweller, J., Kirschner, F. and Zambrano, J., (2018).

2 Research Questions: 1.What effect does watching a practical video with a procedural voice over and a conceptual voice over have on student attainment ? 2.What effect does combining watching the one video with two voice overs with a procedural story board and collaborative learning strategies have on student attainment?

3 Method: Three equivalent teaching groups of 30 students aged 14-15 years completed the making salts exam specification practical task. The teacher of each group followed the pedagogic approach described in Figure 3. The control followed a traditional pedagogy and did not access the teaching resources produced for this study.

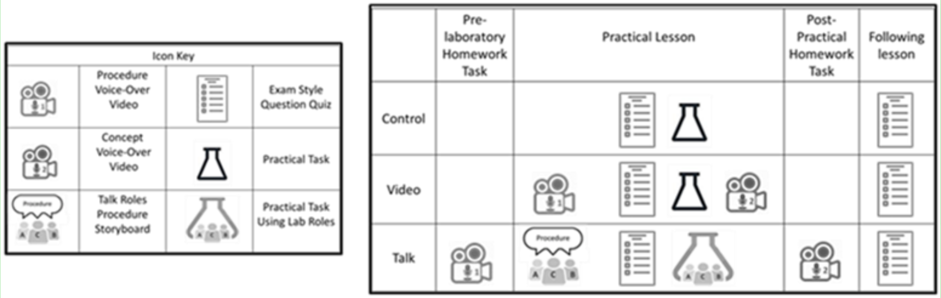
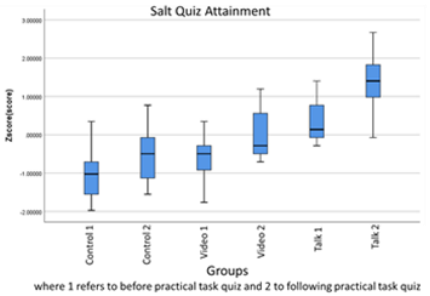


Figure 3 The different pedagogic approaches taken to the making salts practical task. Only the third group titled “talk” used the laboratory task and talk roles and had the one video two voice over resource provided as home learning activities. The group “video” watched the resource in the lesson prior to and after the task



where 1 refers to before practical task quiz and 2 to following practical task quiz

Figure 4 The results of the students’ performance on the test taken immediately before the practical task (1) and then the following lesson (2).

4 Results: Attainment z-scores for each of the groups have been plotted as box plots (Figure 4), a one-way ANOVA was conducted to compare the effectiveness of the three pedagogic approaches F(5,135)= 43.035, *p*=0.0005. Post hoc tests using the Bonferroni correction revealed that all three groups showed statistically significant difference between their test z-score 1 and z-score 2 (p = 0.0005). The talk group’s attainment in test 2 showed a statistically significant increase than those of either the control or the video group (p = 0.0005).

5. Research Question Response: 1.Watching the video with two voice overs immediately prior to and after the practical task (video group) did not produce a statistically significant increase in attainment as compared to the control group. 2.Combining watching the video with two voice overs with a procedural story board and collaborative learning strategies produced a statistically significant increase in students’ overall attainment .

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