Developing perspectives of knowledgeability through a pedagogy of expressibility with the Raspberry Pi

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List of abbreviations (in alphabetical order)

CAS	Computing At School
CFA	Confirmatory Factor Analysis
CPD	Continuing Professional Development
CS	Computer Science
CSTA	Computer Science Teachers Association
EFA	Exploratory Factor Analysis
ICT	Information and Communication Technology
IFTF	Institute For The Future
ISTE	International Society for Technology in Education
IT	Information Technology
NAACE	National Association of Advisors for Computers in Education
RPi	Raspberry Pi
SDR	Shut Down or Restart?
STEAM	Science, Technology, Engineering, Arts and Mathematics
STEM	Science, Technology, Engineering and Mathematics
STEMNeT	Science, Technology, Engineering and Mathematics Network
TAP	Think Aloud Protocol
YRS	Young Rewired State

Abstract

The curriculum for ICT in UK schools was discontinued in September 2012 and replaced by a 'rebranded' subject of Computing, divided into three sub domains: Computer Science; Information Technology; and digital literacy. The latter was positioned as basic technical skills. There were concerns in the education community that the new curriculum promoted programming and computer science topics to the detriment of digital literacy and applied uses of technology. Much of the Computing education literature perpetuates the hegemony of the logical and abstract, and implies computational thinking and rationality are synonymous with criticality. During the same period, a maker culture was growing rapidly in the UK, and discourses around these activities promoted an entirely different notion of digital literacy, aligned with the wide body of literacy literature that focuses on notions of empowerment and criticality rather than basic functional skills. A digital maker tool called the Raspberry Pi was released with the intention of supporting the development of computer science and digital making competence, and thus sat at the boundary of the academic and maker communities. This thesis argues that developing 'criticality' is a vital component of Computing education and explores how learning activities with the Raspberry Pi might support development of 'criticality'.

In setting the scene for the investigation, I will first explore the notions underpinning discourse around both computational and critical thinking and digital literacy, suggesting that the frictions would be best overcome by abandoning abstract constructs of knowledge and assumptions that it is possible to separate theory and practice. I show how the term 'critical' is itself problematic in the literature and I look to Wenger's social theory of learning to avoid the individualistic limits of Papert's constructionism, a popular learning theory in Computing education. Wenger's constructs of knowledgeability and competence help tell a different story of what it means to be a learner of the practice of Computing, both in learning for academic purposes and with intentions towards becoming a practitioner. In concert with learning citizenship, these constructs offer a more ethical framing of 'criticality'. Informed by this theoretical position, I suggest an original, exploratory implementation of Q methodology to explore learning with technology in school settings. I qualitatively compare 'before' and 'after' Q studies that represent perspectives at the individual and collective level, with reference to observations of classroom learning. The methodology facilitates a nuanced and complex investigation and the findings of the project suggest that where pupils are already predisposed to the subject, working with the Raspberry Pi develops a broader knowledgeability, but where there is no such predisposition, a pedagogy of expressibility influences how participation in Raspberry Pi learning activities may impact knowledgeability.

Declaration

No portion of the work referred to in the thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

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Thanks to my girls whose own learning helped me to make sense of every voice I encountered on the way, but more importantly whose existence helped make some sense of the reason for embarking on, and seeing through, such a task as this at all. I hope that with hindsight this particular journey will turn out to have been worth the costs.

Thanks to Steve for patiently travelling with me … "*Part of you, flows out through me, in these lines from time to time*".

The Author

The author has a BSc in Computer Science and was a software engineer for two years before working in an educational technology company and becoming, very briefly, a secondary ICT teacher. I began this PhD journey while working as a Learning Technologist in a UK university School of Computer Science, predominantly supporting academics in developing Masters level course online material in subjects such as BioHealth Informatics and Semantic Web technologies.

In 2009, while working at the university, I heard about the first Computing At School hub, based in Cambridge, and began an equivalent in our area. I felt that such a group would have been a huge support to me while I was teaching, and hoped to provide this support to other teachers. The first meeting was attended by four local teachers, but within two years, there were regularly forty teachers attending meetings and workshops, and additional hubs were set up across the region to cope with demand. Having done this voluntarily for four years, as CAS became the subject association for Computing, I then worked for the organization, coordinating teacher CPD provision in the region, for the 2014/2015 academic year. I also worked as a support tutor for a PGCE in Secondary Computing course during this time.

The author's research experience is limited to this project, the work done for an MSc in Educational Research, which explored Computer Science undergraduate experiences of Enquiry Based Learning, and a project exploring the development of communities of practice through the NHS clinical bioinformatics professional development programme.

Introduction

"… the fundamental ingredients of educational innovation must be better things to do and better ways to think about oneself doing these things" (Papert, Teaching Children Thinking)

There are ways of thinking that we don't yet know about (Rich, Of Woman Born)

Recent changes to the UK national curriculum reflect a demand from industry for more graduates with digital skills. The increased focus on Computing in the curriculum could also be seen to reflect the demand for access to coding for all, from those who view coding abilities as a means of empowerment in an increasingly digital world. During the last few years a large number of educational innovations have sprung up to teach children computational skills in some form, both within formal education and informal learning contexts, most of which attempt to address both the skills and empowerment agenda to some extent. The Raspberry Pi is one such educational innovation, a physical artifact, designed to help young people get closer to the physical structure and concepts behind the technologies they use on a daily basis, to support them in becoming creators and not just consumers of technology.

But as this thesis will show, these innovations have appeared in a sea of confusion around the meaning of the terms, Computing, computational thinking, Computer Science (CS), Information Technology (IT) and digital literacy, the latter being demoted within the curriculum to a definition of basic skills, such as switching on a computer. There is confusion around the purpose of these terms in education and their associated pedagogies.

This thesis will examine the literature to explore how the prevailing discourses around these meanings will at the very least limit how successful these educational innovations for Computing can be within formal education. I will draw on social theory to suggest an alternative discursive framework, through comparison with the purposes, pedagogies and discourses around the computational teaching innovation of the 1980s, Papert's Logo and the Logo Turtle. I will argue that a more critical notion of digital literacy is vital for Computing education, and use a social theory framework to explore learning design around the Raspberry Pi, in four learning contexts, in terms of developing this criticality. Thus the original contribution of this thesis is, firstly, in the application of a theoretical framework that is not usually applied in Computing education to inform a methodological design that applies Q methodology in an original way. Secondly, substantively, the thesis provides insight into the development of criticality through design in the service of learning Computing with the Raspberry Pi, within the confines of our balkanized curriculum.

A new Computing education innovation and a new curriculum

The Raspberry Pi (RPi) was released in early 2012 with great expectations in the Computing community for the impact it would have on Computing education. This tool was developed in response to a perceived lack of interest from children in the subject of Computing. The motivation behind the development of the RPi had an explicit emphasis on getting children interested in Computing, and any focus on developing ‘computational thinking’ through use of the RPi was advocated for its own sake, not as simply one thinking tool to raise students’ awareness of their own thinking. Eben Upton who invented the RPi acknowledged the original intentions: "We honestly did think we would sell about 1,000, maybe 10,000 in our wildest dreams. We thought we would make a small number and give them out to people who might want to come and read computer science at Cambridge” (Heath, 2013). In reality, at the time of the release, there was already a waiting list of 250,000 with the manufacturer.

The perceived lack of interest in the subject of Computing also contributed to the disapplication in September 2012 of the UK curriculum for ICT. A new curriculum was introduced to schools in September 2014, which rebranded the subject as Computing. It restructured the subject into three areas: the academic discipline of Computer Science; Information Technology; and digital literacy as the third element, defined as the basic skills needed to work a computer.

Simultaneously, a maker movement was growing and projects around digital making were promoting coding for all, through out-of-school club organisations, groups such as STEMNET (Science Technology, Engineering and Maths Network) and related events, and works such as ‘Program or be programmed’ (Rushkoff, 2010). The RPi appeared to be a potential bridge between formal and informal learning settings, between the academic, abstract focus of ‘computational thinking’ and the practical and constructionist focus of digital making.

Over forty years ago, another educational innovation within Computing education was developed which showed great promise as a similar medium between scientific and practical perspectives and yet which failed to gain the traction and have the impact that was hoped for: Seymour Papert’s Logo (see for example Papert, 1970). Logo was designed with arguably greater, and now in 2016 even more pertinent, ambitions than the RPi. In *Mindstorms* (1980), Papert described his work to develop ways of thinking through the use of a new programming language called Logo and the associated simple robot, the Turtle. This wasn’t intended to be a way to teach coding for its own sake, and it wasn’t a way to encourage more children to learn to code, although these may have been additional outcomes from the project. Rather it aimed to develop ‘epistemological pluralism’, by which Papert meant developing an awareness of the multiple ways in which one is able to think and to learn complex concepts (see Turkle and Papert, 1990). Two other themes that emerge strongly from Papert’s Logo and subsequent related work were constructionism and technocentrism. Constructionism was the theory of learning he developed, based on his work with Piaget, that focused on learning through creation of a public entity. Technocentrism was his term for concerns about the way in which research and educators focused on tools rather than the broader context in which learning tools are set. These themes will be explored further in the following chapters.

In line with Papert’s three themes, this thesis aims to explore the development of thinking through applying appropriate theoretical frameworks and methodology to explore this development. In the first half of this thesis I will explore the current discourse and literature of Computing education and argue that developing perspectives that we would use the term ‘critical’ to refer to is imperative for Computing students. But key terms in the field, such as computational thinking, critical thinking and digital literacy have been misappropriated in such a way that pedagogies to enable this development are limited. I will suggest that social theories of learning offer better alternatives for the language that guides practice and exploration of practice. I will describe a methodology, Q methodology, which can enable exploration of learning in a way that is compatible with social theory and the aims of developing criticality, and avoids technocentrism.

The second half of the thesis will describe a research project to explore learning activities with the RPi using the language of social theory and an original implementation of Q methodology. I look at four UK secondary school based contexts between 2012 and 2015 and explore how the learning design around the RPi has contributed towards the goal of developing ways of thinking in school aged children, with a focus on the criticality and reflective approaches vital to an empowered future, rather than on purely computational thinking, which following chapters will situate as a problematic term. The term learning design in this thesis refers to all aspects of the context that contribute to the planned learning activity, and I will unpack this term further in chapter 5.

Thesis outline and research questions

Over the thirty years since *Mindstorms* was published, technology has made changes to the way we communicate and more fundamentally to the nature of knowledge itself, (Weinberger, 2014). These changes put centre stage the need for new ways of thinking and for what Weinberger summarises as the crucial things we need to teach children to deal with this new shape of knowledge: “how to use the Net, how to evaluate knowledge claims, and how to love difference” (ibid, p.192). In a subject based curriculum that is skills driven, yet claims to allow more freedom for teachers and schools in what and how they teach, (Department for Education, 2013) is it the responsibility of Computing teachers to cover such issues? If so, how can they do this, particularly in secondary contexts when pupils generally have one hour per week of the subject, and are now also expected to learn CS content?

In this thesis I suggest we need alternative frameworks to talk about criticality and ways of thinking, and new methodological approaches, before we can explore learning with a tool such as the RPi. The research questions this thesis asks then are in essence, how do we talk about this concept of criticality, how can Computing education practice develop criticality and how can we explore and evidence criticality? The first half of the thesis unpacks the notion of criticality and suggests why the social theory constructs of knowledgeability and learning citizenship may be more effective. The research questions then become:

- How can we use a social theory of learning to frame the processes and outcomes of “criticality” in order to inform better learning design in Computing education?
- How can the incorporation of Raspberry Pi technologies in learning design support development of learning citizenship and knowledgeability at school level?

- How can Q methodology be employed to explore the growth of knowledgeability and learning citizenship in pupils of Computing, and how can the methodology itself support development of these concepts?

I will explore these questions further through exploration of the literature that leads to the design and implementation of a research project around the use of the RPi in classrooms.

Chapter 1 looks at the rationale for this research project, beginning with more detail of the RPi itself, the political context into which it was released and why there is a pressing need for criticality in Computing education as the shape of knowledge changes. The key terms of knowledgeability and learning citizenship are central to the research questions, but will not be properly introduced until chapter 5: the terms depend on other fundamental constructs in Wenger's social theory of learning, taking an entirely different approach to learning than that which underpins the existing literature I explore, and it is crucial that these terms are not seen as simply a direct replacement for terms such as 'criticality'. Thus chapters 2, 3 and 4 delve into the underpinnings of the literature to unpack how existing key terms are operationalized in problematic ways, justifying the move to this alternative approach that informs the theoretical and methodological direction of the research study.

In chapter 2 I will start to explicate the difficulties in developing and exploring criticality in this subject. I will initially examine the predominant Computing education discourse at the time the RPi was launched. This includes literature around the notion of computational thinking that has driven policy in the UK, particularly the design of curriculum and teacher professional development in Computing provided by the national subject association.

In chapter 3 I will similarly explore both political and academic literature around notions of criticality and digital literacy, for Computing education. I will look at how these terms are operationalized and how they relate to the discourse around computational thinking and also to Papert's epistemological pluralism. I will suggest that current discourses around computational and critical thinking could be presenting us with a pedagogical antithesis, and if the pedagogical forms we use are built on a premise that make it so, the privileging of the computational thinking discourse risks leading the path away from "a radical theory of literacy that takes seriously the task of uncovering how particular forms of social and moral regulation produce a culture of ignorance and categorical stupidity crucial to the silencing of all potentially critical voices" (Giroux, 1987, p.13).

Chapter 4 will attempt to break down the underpinnings of these ideas of digital literacy, critical and computational thinking in order to justify the move to social theory. I will use Vygotsky's critique of Piaget to explore the underpinnings of Papert's constructionism and the limits that this individualistic approach creates. I refer to Sfard's discursive considerations of operationalization and objectification and discuss how these underpin the friction between the computational thinking and criticality discourses explored in the previous chapters. In addition, I will look at how abstraction "level confusion" (Wilensky and Resnick, 1999), suggests we need alternative frameworks for negotiating meaning in the Computing education landscape, and appropriate methods for exploring learning in this context.

Chapter 5 will explore an alternative perspective, Wenger's (1998) social learning theory, and suggest how this theoretical lens may provide a way to transcend the limits of Papert's constructionism and broker the aims of the computational thinking and digital maker discourses, both in the design for and evaluation of learning. In particular I will focus on the concepts of learning citizenship, competence and knowledgeability, the latter which Wenger-trayner and Wenger-trayner (2015) define in relation to each other, neither being individual characteristics, but rather:

> "Whereas claims to competence are negotiated within the politics of competence of a community of practice, claims to knowledgeability are negotiated within the politics of knowledge in a landscape of practice. Learning to become a practitioner is not best understood as approximating better and better a reified body of knowledge. Rather it is developing a meaningful identity of both competence and knowledgeability in a dynamic and varied landscape of relevant practices" (ibid, p.23).

I will discuss how the tenets of this theory provide more clarity in framing the means and ends-in-view for the subject of Computing, and as a theoretical lens through which to explore design in the service of learning the practice of Computing. Additionally the notion of learning citizenship will draw in the value judgment or ethical aspects of criticality. Wenger explains:

> "Learning citizenship is the personal side of a social discipline of learning. Its ethical dimension arises out of a recognition that each of us has a unique trajectory through the landscape of practices. This trajectory has created a unique point of view, a location with specific possibilities for enhancing the learning capability of our sphere of participation. From this perspective, our identity, and the unique perspective it carries, is our gift to the world" (1998, p. 197).

In Chapter 6 I will introduce Q methodology and describe how this has informed the research design of this project around RPi learning activities. Q methodology, predominantly used in the psychological sciences, is traditionally used to explore shared subjectivities or perspectives. A set of statements is developed, drawn from interviews and literature, which ideally represents "the 'concourse' of what we know to be sayable about the issue in question" (Stenner Watts, and Worrell, 2008, p.219). Participants perform a sorting activity with a set of statements to represent their perspective at a particular moment in space and time, which I will discuss in the Q chapter as representing, in this project, a snapshot of the students' identity as a Computing student. I will explain how the act of performing the sort can be seen as a moment of orientation within the landscape of being a Computing student. I will then explain the novel implementation of Q for this project, employing a qualitatively comparative approach in combination with observational data. This first half of the thesis covers a wide and complex ground, so at the end of each of these chapters there is a summary of key points raised.

The second half of the thesis presents the data and analysis from the substantive research project. Chapter 7 details the four learning contexts explored and other methodological implications, such as ethical considerations. I will describe each situation in detail, including the practicalities of data collection informed by Q methodology and the associated interviews and observations, which differ depending on the contextual factors.

Chapter 8 provides the substantive analysis of the data in relation to the second research question, starting with a Q analysis of perspectives or subjectivities of the students as drawn from two Q sorts, one before they work with the RPi, and one after. Chapter 9 describes the qualitative comparison of the Q studies in conjunction with the additional data from interviews and observations, to explore how students' thinking about the subject, and their consequent self-positioning within the landscape of their practice as students of Computing, may have changed during the period in which they worked with RPis.

Chapter 10 draws on this analysis to discuss what aspects of the learning scenarios using the RPi may have led to pupils' changes in perspectives and Chapter 11 presents the conclusions from the research project, referring to the data to reflect on how well the research questions, relating to theoretical framework and methodologies, have been answered, exploring possible critiques of the research design and implementation, implications of the analysis for research and practice and potential future directions for research.

Chapter 1 – The UK Computing Education Landscape

"What matters most is that by growing up with a few very powerful theorems one comes to appreciate how certain ideas can be used as tools to think with over a lifetime. One learns to enjoy and to respect the power of powerful ideas. One learns that the most powerful idea of all is the idea of powerful ideas" (Papert, Mindstorms).

Introduction

In this chapter I will look at the landscape of Computing education in the UK, beginning with a high level overview of the changes and influences over the last few decades, and outline the concerns and opportunities developing along the fault lines of key competing discourses. I will show how many of the concerns being expressed currently, by both the academy and industry, mirror concerns in the 1980s at the same time as Papert's (1980) Logo project was evolving in the United States. Technology is arguably having an increasingly disruptive effect on education, (see for example: Christensen and Eyring, 2011; Roomer 2014; Magid 2013) which may provide the RPi and other recent Computing focused educational innovations with a foothold that Logo was denied. However, when we juxtapose the discourses around Computing in formal education and those of digital making, we can see the former are still instrumental and technocentric and in danger of, not only limiting the impact of such innovations, but moving education further away from supporting the adaptive and creative abilities that our technological culture demands. I will argue that this stems from the underlying theories of learning and associated language that hold sway in the Computing education field. I will introduce the RPi - the tool, the project and the phenomenon - and then ask what exactly we need from our Computing education and why, in order to begin the exploration of how learning with the RPi might support this.

1.1. From Computer Studies to ICT to Computing in UK Schools

In 1980, Mitchell had predicted a spiralling decline in the quality of Computing education in the US, due to an increased market demand for skilled computer scientists. He predicted this would draw graduates away from education, make Universities unable to recruit adequate staff to meet that market demand, and so, "that demand is intensified and more of the existing faculty and students are lured away" (1980, p.204). He suggested that this would be reflected at high school level, and refers to Taylor et al who suggest, "every teacher at the elementary and secondary levels should possess computer competencies in programming, analysis, educational applications, and societal impacts of the computer" (ibid, p.203). Mitchell's question is who will teach this to the teachers if Universities can't recruit specialists in this area? His overall prediction was that, "Computer education will be provided, and it will be delivered to an ever expanding audience, but its quality in the 1980s will range from mediocre to terrible" (ibid, p.205).

At this time in the UK education system, there were several qualifications in Computing for 16 to 18 year olds, but from 1988, when the subject of Information Technology was introduced, to 2003 when A Level Computing was split into ICT and CS, the number of students taking Computing qualifications at school declined. Concomitantly, university applications to Computing degree programmes reduced (Brown, Kolling, Crick, Peyton Jones, Humphreys and Sentence, 2013; Bradshaw and Woollard, 2012). This decline continued over the next decade, despite increasing reports about a shortage of computer scientists in industry.

In 2008, a grassroots group called Computing At School (CAS) was formed with the intention of improving CS education in schools in the UK. The group began informally with teachers, academics and industry representatives who were concerned with the declining numbers studying Computing and the heavy focus on ICT within the curriculum at the expense of CS. In 2012 the group became a member of the Council for Subject Associations and through lobbying activity, developed a growing influence within UK education (Brown et al, 2013).

1.2. UK PLC

In 2011, The Next Gen report, produced by leading figures in the UK's games and visual effects sectors, bemoaned a shortage of creative programmers and "a school curriculum that focuses in ICT on office skills rather than the more rigorous CS and programming skills which high-tech industries like video games and visual effects need". (Livingstone and Hope 2011). This message was echoed in part of a lecture given by Eric Schmidt (CEO of Google since 2001, but a few months before his speech had stepped down and become the Executive Chairman) later that year stating within the hour long lecture that, "I was flabbergasted to learn that today computer science isn't even taught as standard in UK schools. Your IT curriculum focuses on teaching how to use software, but gives no insight into how its made. That is just throwing away your great computing heritage." (Guardian, 2011) Following this speech, the bandwagon was well and truly rolling and media organisations such as the BBC and Guardian began projects to raise awareness of digital skills issues, the BBC's (2013) work leading to the "Year of Code" and "Make it Digital" projects, and the Guardian launching their "Digital Literacy" campaign "to upgrade computer science and IT in schools" (Guardian, 2012).

On January 11th 2012, Michael Gove, the then Secretary of State for Education, gave a speech at the BETT conference (Department for Education, 2012), in which he announced the withdrawal of the National Curriculum Programme of Study for ICT from September of that year. In the speech he referred to CAS, the Raspberry Pi project, Eric Schmidt's speech, the Next Gen report and to the Royal Society's report, which was published in the same week as Gove delivered his BETT speech. This latter report titled *Shut down or restart? The way forward for Computing in UK schools* (Furber, 2012), subsequently became the driving force behind terminology change, curriculum content and the supporting documentation for teacher continuing professional development (CPD) promoted by the CAS group.

1.2.1. Shut down or restart?

The Royal Society launched their project, ‘Computing in Schools’, in 2010. Professor Steve Furber, who had himself been a principal designer of the BBC Micro and the ARM microprocessor, around which the RPi is designed, chaired the study. The advisory group for the report consisted mainly of academics and key members of the board of CAS. A call for evidence drew one hundred and twenty six responses, some of which were representative of group memberships, providing “reflective comments and suggestions of relevant reports”(Furber, 2012, p.14). This was followed by stakeholder workshops, separated according to audience: teachers; higher education; and ‘others’. The report doesn’t say who was invited to these workshops or whether they took place at a time that enabled working teachers to participate. Research was commissioned to analyse this evidence and further sources such as existing surveys and UCAS data, but detail on what form this analysis took is not given.

The motivation for the project was the reduced uptake of CS at school level, and high attrition rate of students after their first year of HE in CS related subjects, which the report claims is due to misconceptions of what the subject area entails. They reported “a 60% decrease since 2003 in numbers achieving A-level Computing, down to just 4,002 in 2011; a 34% decrease at ICT A-level over the same period; and a 57% decline in ICT GCSE during 2006 – 11” (Furber, 2012, p.14). The report suggests that the primary reason for this decrease in uptake was due to teachers who were unable to provide inspiring content that took advantage of a broad curriculum due to many being non-specialist, a lack of professional development and inhibiting school infrastructure (ibid, see for example p.4 and p.5). They also refer to: a lack of understanding of what CS as a subject is; a lack of opportunity for students to learn about Computing; and ineffective qualifications and assessment mechanisms (ibid, see for example, p10-p.11).

They recommend that in order to address these issues, rebranding ICT and “disaggregating” it into digital literacy, Information Technology and CS should be considered. As part of this very first recommendation they present this as an analogy “with how English is structured at school, with reading and writing (Basic literacy), English Language (How the language works) and English Literature (how it is used)” (ibid, p.8). The definitions of these three content areas and the umbrella term ”Computing” are given as:

> “Computing: The broad subject area; roughly equivalent to what is called ICT in schools and IT in industry, as the term is generally used.
>
> Computer Science: The rigorous academic discipline, encompassing programming languages, data structures, algorithms, etc.
>
> Information Technology: The use of computers, in industry, commerce, the arts and elsewhere, including aspects of IT systems architecture, human factors, project management, etc. (Note that

> this is narrower than the use in industry, which generally encompasses Computer Science as well.)
>
> Digital literacy: The general ability to use computers. This will be written in lower case to emphasize that it is a set of skills rather than a subject in its own right" (ibid, p.5).

Digital literacy is placed here at a very basic functional level, yet in putting the educational case for each of the three sub-disciplines of Computing, the report claims that all three are empowering. The report suggests that digital literacy is "fundamental to participation" (ibid, p.28) in society. The case for Information Technology is summarised as, "[IT] can be considered to be an 'empowering' [sic] subject in the sense that it can underpin creative expression, meticulous design and realisation, effective analysis and use of information and safe and secure social participation" (ibid, p.30). In the educational case for CS, the report suggests, "Citizens able to think in computational terms are able to understand and rationally debate issues involving computation, such as software patents, identity theft, genetic engineering, and electronic voting systems for elections… The CS student has unprecedented freedom over what, and how, to create" (ibid, p.29). This association of computational thinking with rationality mirrors the hegemony of the formal and abstract that Turkle and Papert (1990) discuss, and will be explored more in the first half of the thesis, as this is symptomatic of the perspectives in Computing education that undermine what we generally mean by the term criticality.

1.2.2. The Response to Shut Down or Restart?

Following the publication of the report there was considerable backlash against what was seen as an "anti ICT" perspective, and concern among many about the marginalisation of digital literacy (see for example Harrison, 2013). The government was very supportive of promoting CS as a 'rigorous academic discipline', as demonstrated by the new curriculum that was released in September 2013, which emphasised this aspect of the triad heavily.

The impact of such a dramatic change in focus for ICT teachers, many of whom did not start teaching even the previous ICT curriculum as specialists, was a huge and immediate need for CPD in CS topics, which there is an on going attempt to address (some might say exploit) by educational consultants, training companies, local government, academia and groups such as CAS. This provision is predominantly focused around coding and covering aspects of exam board syllabi. Much of what is currently available to teachers, both in the CPD arena and in the increasing number of online resources in websites such as CAS and NAACE, refers to the Royal Society report and uses their tripartite division of the subject. This includes the *Computing in the National Curriculum Guidance* documents for primary and secondary, which the CAS group sent to all head teachers across the UK in November 2013.

1.2.3. Contradictions and corollaries

Close reading of the report would suggest the political agenda of the authors of *Shut down or restart?* was to ensure the inclusion of the subject within a national curriculum designed to return to more conservative values. The problem begins with the need to have the subject perceived as academically “rigorous” and as one of the sciences, on a par with Physics and Maths. The report suggests only those with “an aptitude for the subject” (Furber, 2012, p.6) will be able to cope with the academic nature of the work involved.

Yet the essential rationale for studying the subject is that it develops a new way of thinking, new approaches to problem solving, falling under the umbrella of ‘computational thinking’. The primary justification within the report for including the subject in key stages 1 to 3, is that these ways of thinking will be of benefit to all students in a world that increasingly relies on technology, where all jobs will require digital skills (ibid, p.29). The industry demand for skills is given as the fundamental driver for the suggested changes, yet notions of ‘vocational’ (see for example, ibid, p.11 and p.21) in the Royal Society report are defined in opposition to ‘academic’, rather than suggesting something like Dewey’s interpretation of “vocation” as a calling, as: “nothing but such a direction of life activities as renders them perceptibly significant to a person, because of the consequences they accomplish, and also useful to his associates" (Dewey, 1916:1980, p.316).

The report exacerbates this through the divide into three subject areas, which they claim will “span” (rather than perhaps transcend) the “traditional academic-vocational divide” (Furber, 2012, p.23). But the pedagogy for such a triad is problematic: analogies are drawn with the three natural sciences (ibid, p.11), which are taught as one combined subject until key stage 4, at which point students can specialise in one of the three. But this is based on those three sciences being viewed as on an equal footing academically, which is explicitly not the case for the Computing trinity. This was emphasised in November 2015 by the removal of any ‘academic’ qualifications in Information Technology as of September 2017 (Department for Education, 2015). Only ‘vocational’ qualifications will cover this aspect of the subject.

This latter issue again caused concern for many educationalists and an online petition calling for ministers to reconsider raised over 10,000 responses. With this number the government was forced to respond, but essentially just reiterated their position in the qualifications consultation document in which the announcement was made (Department for Education, 2016). This position showed a continuation of emphasis on “rigorous”; an instrumental discourse privileging industry needs; explicit acknowledgement that CS is the key area of the subject; and reference to “computational thinking skills”, which are conflated with coding.

1.3. The problem with “computational thinking”

This key term of computational thinking, which is said to underpin the whole subject area of Computing, is contended in the literature. Chapter 2 will explore the discourses around this term, predominantly from the UK and U.S. perspectives. But in these discourses, there is more at stake than simply the privileging of the academic over the vocational: there is also the privileging of the scientific over the concrete and the “hegemony of the abstract, formal, and logical as the privileged canon in scientific thought”, (Turkle and Papert, 1990), which contributed to Papert’s frustrations in the Logo project (see also Papert, 1987b). He saw the computer and its place in education as a medium to transcend the knowledge/practice divide. He explained how “the computer can concretize (and personalize) the formal” (Papert, 1980, p.21). But in order to take advantage of this medium in such a way “requires an epistemological pluralism, accepting the validity of multiple ways of knowing and thinking” (Turkle and Papert, 1990, p.1). Turkle and Papert observed a number of participants newly introduced to programming and taking part in a course which teaches one “right way to approach the computer” (ibid, p.3) but which doesn’t necessarily work for the intellectual styles of the students: “Lisa says she has "turned herself into a different kind of person" in order to perform… [participants] deny who they are in order to succeed” (ibid, p.3).

There are two significant predicaments to face from this work by Turkle and Papert. The first is the idea of the learners denying who they are and the participant “turning herself into a different kind of person” to succeed in Computing. This interpretation situates learning as a process of identity, as a social becoming, and yet this is lacking in Papert’s constructionist theory. A social perspective of identity is central to the social theory of learning I will explore in chapter 5, which informs the design of my research project.

The second issue is ‘epistemological pluralism’, lack of which is problematic from all pedagogical perspectives. Turkle and Papert describe an attitude to teaching Computing which does not allow for a concrete and personal ‘ways in’ to the subject. They explain that although:

> “… there has been a systematic construction of the computer as the ultimate embodiment of the abstract and formal … Computers provide a context for the development of concrete thinking … The practice of computing provides support for a pluralism that is denied by its social construction” (ibid, p.1).

A belief in one “right way” to do things has worrying implications for learners as well as educators. CS students generally have a technical background and students of these and engineering disciplines are “used to sitting and listening... learning the correct way to do things” (Bullen, 1998, p.30). But if the students’ underlying epistemic perspective is based on a deterministic “correct way”, this is problematic for critical thinking: for example Chan, Ho, and Ku’s (2011) research with students in HE settings suggests that students who view knowledge as certain have a reduced capacity for critical thinking. The discourse around critical thinking, and how it relates to computational thinking and digital literacy, will be discussed in chapter 3. I will show that some authors suggest there are problems with expecting teachers to develop criticality in their pupils. Stakeholders such as CAS and NAACE (National Association of Advisers for Computers in Education) are very keen to point out that Computing is a relatively new subject and that understanding of how best to teach it is limited, and as

Mitchell warned in the 1980s, the immaturity and breadth of the discipline creates an obligation to ensure the subject area as a whole is addressed:

> "Whether we like it or not, people both within and without the university expect that we will provide the expertise and the perspective required to develop the broad spectrum of applications which will be tackled in the 1980s. The less seriously we take these problems, the more grave the consequences for the society and the culture we all share" (Mitchell, 1980, p.206).

Further than just considering the breadth of the subject, teachers are expected to prepare all students for a world that is different to that in which we currently live, regardless of subject. CS is fundamental to many of the changes that are occurring and will continue to be so. Weinberger (2014) explores how knowledge is now a "property of the network" and "the smartest person in the room is the room itself: the network that joins the people and ideas in the room and connects to those outside of it" (ibid, p.xiii). He discusses how the Semantic web, and more usefully linked data, can support us in managing this new shape of knowledge, and these practices are based on computational techniques.

But it is also important to understand the limits of computational thinking in the context of the subject as a whole and in its place as a "property of the network". An interesting report, "Future Work Skills", produced in the US in 2011, takes a skills perspective yet has a more vocational outlook, in the Deweyan sense of vocational: in terms of what skills people will need in the future to participate in meaningful work, as opposed to producing more 'code monkeys' for the benefit of the corporations that need more programmers. This latter concern is summarised by Naughton (2012) who suggests that the moral justification for ensuring children understand technology is greater than any economic motivation, as if they don't have this understanding:

> "…They will grow up as passive consumers of closed devices and services, leading lives that are increasingly circumscribed by technologies created by elites working for huge corporations such as Google, Facebook and the like. We will, in effect, be breeding generations of hamsters for the glittering wheels of cages built by Mark Zuckerberg and his kind" (2012).

The Institute For the Future (IFTF) report describes the drivers for change in the global working environment and how they are "reshaping how we think about work, what constitutes work, and the skills we need to be productive contributors in the future" (IFTF, 2011, p.10). Computational thinking is one of the skills they suggest is needed, but in line with Papert, they emphasise the importance of computational thinking as relative to other thinking tools, and as such, awareness of its limitations is also crucial. Models are simply approximations of reality and "… workers must remain able to act in the absence of data and not become paralyzed when lacking an algorithm for every system to guide decision making" (IFTF, 2011, p.10)

In contrast to Bullen and Chan et al's findings that engineering subjects lead to deterministic mindsets, Papert believed that inviting children into computational approaches to problems could have the opposite effect, and broaden their thinking approaches. His aims were very different to the current discourse of aims for computational thinking, which promotes the concept as an end-in-itself. In 1970, as Papert described early work with Logo, he claims, “The most important (and surely controversial) component of this impact is on the child’s ability to articulate the working of his own mind and particularly the interaction between himself and reality in the course of learning and thinking” (Papert, 1970, p.4). As he defends the work of Logo in 2005, and explains the misinterpretations of what he set out to do with Logo, he says, “Programming can be used to support learning about thinking, which is a very different claim from saying that in itself it improves thinking skills” (Papert, 2005, p.367). The rationale behind Papert’s attempts to develop computational thinking, can most clearly be seen as he anticipates criticism for Logo from those who might understand Logo as encouraging children to think mechanically:

> “By deliberately learning to imitate mechanical thinking, the learner becomes able to articulate what mechanical thinking is and what it is not ... Analysis of "mechanical thinking" and how it is different from other kinds and practice with problem analysis can result in a new degree of intellectual sophistication” (Papert, 1980, p27).

Papert believed that experience of using this “very concrete, down-to-earth model of a particular style of thinking”, would make children aware that there were different “styles” of thinking and in learning new styles and considering how to choose between them, “… these children would be serving their apprenticeships as epistemologists, that is to say learning to think articulately about thinking” (ibid, p27).

1.4. Digital literacy and makers - an alternative position

Around the same period of change in the Computing curriculum, a “Digital Maker” discourse was also gaining prominence around such organisations as Mozilla, Nesta, Google and the RPi community. By the latter I do not mean the Raspberry Pi Foundation that design and develop the technology, rather the groups, educational and informal, that have sprung up around the technology. The UK Digital Skills Taskforce interim report (2014) used the terms Digital Citizen, Digital Worker and Digital Maker to outline tiers of skills. This report suggests digital literacy should be taught across all subjects and not just Computing. They claim that although not all students will go on to be digital makers, an understanding of CS is “useful” and “will facilitate later learning” but in addition, “all children need a grasp of digital literacy (or digital literacies), the web skills you need to consume, create and participate online effectively, responsibly and safely” (ibid, p.34). Digital literacy here is still being defined as a separate entity to CS, and situated as something necessary and important, but basic. A digital maker is defined as:

> “… those who have the skills to actually build digital technology. This could range from less advanced tasks such as writing Excel macros or creating control files for 3D printing to everything from designing the next microprocessor or implementing ground breaking machine learning algorithms” (ibid, p.6).

The notion of a “digital maker” has gained traction over the last decade since the first Maker Faire in San Francisco in 2005, which had around twenty thousand attendees, and three times that in 2008 (Weinberger, 2014, p.143). Crucially, digital making is situated as not simply creating software artefacts, but in combining the digital with other materials, in projects such as “computer-controlled Etch-A-Sketches, biodiesel processing units, biologically-inspired multiprocessors, scratch-built RFID readers, wind-powered generators, networked citizen weather stations", (ibid, p143). This reflects Papert and Harel’s constructionism which “shares constructivism's connotation of learning as ‘building knowledge structures’ … then adds the idea that this happens especially felicitously in a context where the learner is consciously engaged in constructing a public entity, whether it's a sand castle on the beach or a theory of the universe” (1991, p1).

Groups that support children in developing coding skills have grown rapidly during the last few years, including Young Rewired State (YRS), Code Club and Apps for Good, the latter whose goal as an example is:

> “… to produce more able, self-confident, collaborative young people, ready to make a difference to their world. Most children are consumers of technology; we want them to become makers using technology. We are building a new model of education” (Apps for Good, 2015).

These organisations promote a view of coding as an essential skill, often situated as a new literacy, one with a far broader definition than that used by the Royal Society’s “Basic literacy”. Whereas the focus of the latter report was on computational thinking, with coding presented as an aid to teaching these superior ‘thinking skills’, the maker discourse presents coding as fundamental to digital literacy in the way that reading and writing are fundamental to traditional notions of literacy.

In the maker discourse, there is also a strong emphasis on social factors, collaboration, connecting, participating, which are minimal in the individualistic computational thinking discourse. Cathy Davidson (2012b) promotes another ‘thinking’ term, “Algorithmic thinking [which] is less about ‘learning code’ than ‘learning to code.’” In an interview with Mozilla, she goes further in defining algorithmic thinking as a social phenomenon, and one that comes with an inherent attitude or perspective:

> “…its about citizenship and its about participation … We need to be training youth who have a passion for contribution and participation, a passion to keep the Web open, and a passion and practice of democratized participation. That is their 21st century inheritance” (Davidson, 2012a).

1.5. Raspberry Pi

The Raspberry Pi (RPi) was designed to be a "catalyst" (Raspberry Pi Foundation, 2013b). The idea and original design was developed by a small group of academic computer scientists at the University of Cambridge, who were troubled by the decline in interest in the subject. They felt that:

> "Something had changed the way kids were interacting with Computers. … the colonisation of the ICT curriculum with lessons on using Word and Excel, or writing web pages; the end of the dot-com boom; and the rise of the home PC and games console to replace the Amigas, BBC Micros, Spectrum ZX and Commodore 64 machines that people of an earlier generation learned to program on." (ibid)

The RPi is just a little bigger than a credit card and cost around £25 when it was first released. The aim was to provide a low cost computer to increase access in the hope that it would be "used by kids all over the world to learn programming" (ibid), following the model of the BBC Micro in the 1980s. The latter was developed as part of the BBC "Computer Literacy" project (National Archive of Educational Computing, 1983), which sold the BBC Micro predominantly into schools, with supporting materials and a TV series about programming. Similarly, the initial focus for the RPi was around school learning, but over the first year after the launch, the RPi Foundation moved their educational focus more towards informal learning contexts.

The RPi was released on March 1st 2012. Despite the anticipation from hobbyists and the large waiting lists, the reaction from teachers was mixed. While some teachers started to use the RPis in both timetabled lessons and after school clubs, at the time of writing, discussions on the CAS forums and my own experience visiting schools for teacher CPD and mentoring trainee teachers, suggested that many bought RPis and related equipment that was rarely if ever used, as the setup and realities of using it in a classroom were more restrictive than they expected. The BBC launched a 'Make it Digital' project in 2015, part of which was the Microbit, a much more simple but equally low level board for educational purposes, in part as a recognition of the difficulties faced around using RPis in school settings, and an attempt to address these.

In January 2013, Google announced they would be funding the RPi Foundation to give 15,000 RPis to "schoolkids around the UK" (Raspberry Pi Foundation, 2013a). A member of the Raspberry Pi Foundation posted on the CAS community site at the time that: "The Foundation's main concern is that they get used and loved, rather than stuck on a shelf or re-sold on Ebay. Our model is to get them into the hands of users, rather than wait for the school infrastructure and formal teaching structure to catch up" (Lang, 2013). There was no recognition of the potential elitism of this approach, despite recognition in the Shut Down or Restart report that "If non-formal learning activities are undertaken voluntarily by students, then there is likely to be the potential to influence attitudes towards a subject (albeit within a self-selecting group)." The self-selecting group would be likely to be those with an existing interest in or inclination for the subject, often those with parents or family with experience connected to Computing. Although the point is raised in the report, it is trivialised through the placing of parentheses as if it is of little concern. Again, the focus was all around supporting pupils with an existing interest, or ‘aptitude’, rather than reaching out to all students who may not previously have had access to the technology or the subject area.

However, although the popularity of the RPi seemed to lie with informal learning contexts, the Foundation did not give up on formal education, and began to invest more effort into promoting use within schools, by employing a teacher to work with them, setting up free teacher training courses through an initiative called Picademy and supporting national competitions around RPi projects. One of the outputs from this collaboration was a set of lessons based on coding music, called Sonic Pi, and this was used in two of the learning contexts explored in this project.

At the time the RPi was released there were already a number of similar tools that were used in schools, predominantly in Design Technology lessons. Arduino is perhaps the best known of these, but there are many more. The potential for what is possible with an RPi is greater due to its processing power, but this was not going to be a motivating factor for teachers just starting out with these kinds of tools. The RPi gained momentum due to the profile raised by the community that grew around it. This emerged predominantly through hobbyists, who appreciated the technical potential, and through the position, both politically and geographically of the Foundation members, who were all except one based in Cambridge, with strong connections to the University of Cambridge, Microsoft, Google and Broadcom (who manufactured the boards). A Computing teacher from Preston, with a background as a DT teacher, began to hold ‘Raspberry Jams’, where pupils, parents, grandparents and other teachers could come along and see what they could do with an RPi, and learn some coding in the process. These events were sometimes organised and run by young people, one such example being thirteen year old Amy Mather, who gave a presentation on her coding at the first Raspberry Jamboree and subsequently won European Digital Girl of the Year 2013 (see http://www.tech4goodawards.com/finalist/amy-mather/). The jams took off in other areas across the UK and also in the U.S. and Singapore. Larger events, Raspberry Jamborees, were then also held with support from organisations including the BBC and STEMNet.

The awareness of the RPi that all of this activity raised, had a snowball effect, such that many people using them created and shared resources, example projects and other learning materials, that teachers could use as a starting point. There were lots of forums on which use of the RPi was discussed and troubleshooting advice given, and groups such as CAS were looked to for advice on how to use it in a classroom. One high profile project was Dave Ackerman’s Pi in Space project (see http://www.daveakerman.com/), which inspired one of the learning contexts in this project as they aimed to emulate the launching of a device into the atmosphere to relay photos of the Earth with a webcam. This required the use of an interface board that allowed the RPi GPIO connections to plug easily in to other devices, and a number of these were developed very soon after the release of the RPi. Another project developed Minecraft Pi, which provided a more basic version of Minecraft that could run using the limited processing power of the RPi, and allow users to code Minecraft, to create objects and behaviours that were additional to the features provided intrinsically within the game. Both the Minecraft feature and some interface board activities using the PiFace board, were used by one of the learning contexts in this project.

All of this was happening at a time when teachers' ability was being undermined by the reports such as *Shut Down or Restart?* (henceforth SDR) which lay the blame for reducing numbers of applications for Computing courses squarely at the door of teachers. Many teachers were looking for a way in to the new Computing curriculum that would be inspiring for their pupils, but manageable for those with little experience, particularly in the coding aspects of the subject. The maker community and the school community were overlapping around the RPi. In the North West, the STEMNet schools team ran events for teachers that were tied in with their maker fair, and used the RPi as a focus for this. This drawing together of informal and formal learning contexts, and the maker and computational thinking discourses, was the reason I wanted to explore the learning designs around this tool in particular, rather than the Arduino or other similar technologies.

1.6. Lessons from Logo

Agalianos, Noss and Whitty (2001) explore the Logo project, situating the Logo language as a tool that is socially shaped and both subject and object of negotiated meanings. They suggest there were two approaches by educationalists in implementing Logo: those who saw it as a potential for grassroots change from within the system, the reformers; and those who saw Logo as challenging existing perceptions of education, as an 'anti-school' phenomenon, the revolutionaries. They discuss two main structural factors that limited the potential of Logo: the organisational culture of schools, and the political context into which it was released.

In order for Logo to achieve the reformation hoped for, teachers would need to accept being co-learners and give up traditional views of hierarchy and the position of teacher as expert, which they claim many teachers were reluctant to do (ibid, p.486). They further suggest that Logo challenged traditional subject divisions and teaching styles within "traditional subject subcultures" (ibid, p.488), but rather than effecting change in this system, Papert (1993a, p.38) explains: "little by little the subversive features of the computer were eroded away: instead of cutting across and so challenging the very idea of subject boundaries, the computer now defined a new subject". In terms of educational culture, "Logo was in most cases undesirably disruptive as it meant that the culture should change its values and habits to implement it" (Agalianos et al, 2001, p.485).

In terms of the political context, the discourse of the time that Logo entered mainstream schools was "Back to Basics". Agalianos et al say, "official policy-making circles then pre-occupied with the 'computer literacy' campaign were quick to link Logo up to the popular rhetoric of the time" (ibid, p.490). They describe how schools decided to use Logo, "without any well-formulated educational rationale. Within the context of the 'computer literacy' campaign, 'learning Logo' became an end in itself, lending schools the glamour of the new technology; Logo became an accessory to a technocentric way of thinking about education" (ibid, p.490).

The lessons that Agalianos et al suggest such educational innovations need to take from the Logo experience, are that the, "gap between the initial expectations and the reality of its implementation demonstrates that the technology needs to be surrounded by social and political relationships that will allow it to do transformational work; that the introduction of technology alone cannot possibly bring about radical change; that the medium alone cannot carry the entire message" (ibid, p.498). They express a small glimmer of hope for transformation through Logo's descendents, but are generally negative about the possibilities:

> "… there is still some space for a radical appropriation at conducive local environments that value alternative approaches to teaching and learning. Yet, in the current context, they seem likely to remain marginalised in the absence of a wider transformation of the structure and culture of contemporary schooling" (ibid, p.498).

Papert was more optimistic about the opportunity for educational change, based on viewing the system itself in the same way as constructionist theory views individual learning, and perhaps the impact of RPi could be greater due to two cultural changes he draws attention to: rather than as an imposed change in structure, he suggests change will be emergent based on forces "… at work that put the old structure in increasing dissonance with the society of which it is ultimately a part, and … ideas and technologies needed to build new structures are becoming increasingly available" (Papert, 2000, p.728)

In looking to the Logo project for inspiration, it is important that the RPi is viewed as socially situated, or we will fall into the trap of technocentrism from the start. Technocentrism was Papert's term to critique the focus on technological tools that was embedded in both learning design and research in education and which consequently undermined both. This was evident in the research questions that others asked of the Logo project in classrooms and also in the methodologies used to explore these questions, which took an approach that Papert referred to as scientism (Papert, 1987a, p.3): "experiments that isolate just one factor and keep everything else the same". He believed that:

> "… in the case of Logo, one sees its absurdity in the fact that the whole point of Logo is to make everything else change. One does not introduce Logo into a classroom and then do everything else as if it were not there. Such an approach completely misses the point. Logo is an instrument designed to help change the way you talk about and think about mathematics and writing and the relationship between them, the way you talk about learning, and even the relationships among the people in the school - between the children and the teacher, and among the children themselves" (ibid, p.4).

Of Logo, Agalianos et al say, "Beyond the few committed enthusiasts who already had a vision, the reaction of teachers and the ways in which Logo was taken up were uneven, depending significantly on the views of individual teachers as well as on the culture of the specific school environment in which Logo was being introduced" (2001, p.485). If we are to avoid technocentrism, and acknowledge that we can't explore the impact or implementation of the tool itself, but only of the tool in situ, then these issues of unevenness are to be embraced in the exploration. Consequently this thesis explores learning within four uneven contexts using RPi, employing a new framework for the exploration, which in itself, theoretically and methodologically, works to promote an "epistemological pluralism". This framework is important in terms of providing direction, as Noss made clear in a Westminster Forum debate in 2012 “Next steps for the ICT Curriculum", when explaining that Logo failed to have the desired impact because teachers not only were unclear on how to use it, but didn’t have a clear understanding of why they were using it. He asks “how do we ensure that we don’t try and squeeze this fantastic revolutionary idea into what is a deeply conservative institution, namely schools?” (Westminster Education Forum, 2012). I will argue through this research study that despite the difficulties, there are benefits to squeezing these ideas into schools, if we can use the experiences of Logo to inform the learning design around them.

1.7. The challenge: criticality in Computing?

The first difficulty I faced in designing this project was how to set about exploring learning in a subject whose aims and terms are so contested. Across all the literature, political and academic, there is no coherent message about what students should be learning in Computing or why and the new curriculum deliberately gives very little guidance. There is no consistent definition of what computational thinking is, or of what digital literacy is, only that, within the CS discourse, the notion of “thinking” is at the exalted end of the scale and the narrowly defined notion of “literacy” sits at the other end. There are many references to the need for ensuring students ‘think critically’, but no agreed definition of what critical thinking is, how it would manifest in a way that can be assessed, or how it otherwise relates pedagogically to Computing.

There are mixed messages about whether all students or just those who are more ‘academic’ should learn to code, whether all students should learn computational thinking, whether coding is a tool for, an element or means of computational thinking, or an outcome, an end, and whether one is dependent on the other. Key reports express concern about the lack of Computing subject knowledge held by teachers who have thus far taught ICT, and yet there is no consensus on the fundamental underpinnings of what that subject of Computing is. There are several references to the fact that Computing is a relatively new subject and so knowledge of pedagogy is also limited. The curricula, schemes of work and resources being pushed at teachers from all angles are built on these varying and often contradictory foundations yet despite the chaotic messages, since September 2014, all UK state schools, primary and secondary, are required to teach “Computing”.

Even just the proposed changes in terminology are concerning as Morris, (2012, p.4) suggests: “Instead, it considers the possibility of ‘disaggregating’ ICT into three ‘clearly defined areas’ … although this, arguably, may only succeed in further compartmentalising the use of technical vocabulary.” The effects of these language confusions were more recently highlighted in a session at a Westminster Education Forum Keynote Seminar in December 2015, when Oliver Quinlan of Nesta cautioned that the Secretary of State and others had been referring to the curriculum as a Computer Science curriculum, when it was actually a Computing curriculum, of which CS was just one aspect. (Westminster Education Forum, 2015).

I have given examples above of work that suggests Computing and engineering students are less likely to develop criticality than those in the social sciences. But whether we consider the subject to be exclusively for those with an ‘aptitude’ for the subject, or as essential for all, students of Computing have a particular responsibility to develop criticality, given that they are learning to develop the technologies of the future and this gives them potential for considerable power that they are often unaware of. Zook and Graham’s (2007) paper on Digispace explores how Google’s algorithms privilege certain information, how ranking can be manipulated and how their mapping tools can actually influence how physical space is perceived. They discuss the power of code to shape access and ordering of information, describing an example from a comparison of a search on the Chinese Google site and on Google.com. In 2007, Google China was still based in mainland China and was subject to censorship by the government. A search on the word ‘Tiananmen’ led to images of the place on the Chinese internet site, images of buildings and so on, whereas on the global site, the images were of the 1990 protests in Tiananmen square. Zook and Graham say this:

> “… belie[s] Google’s characterization of its rankings as a natural outcome of a rational process that produces unbiased results. This is not to devalue the usefulness of bringing order and ranking to the Internet but to recognize that it is a socially constructed process subject to direct manipulation” (Zook and Graham, 2007, p.1326).

This raises issues of the power inherent in the ability to create and control code, and Mitchell asks of those who will develop the future technologies that structure our lives, “What shall that software allow and proscribe? Who shall be privileged by it and who marginalized? How shall the writers of the rules be answerable?” (Mitchell, 1996, p.112). More recently Harford has highlighted the increasing automisation of our world and he warns, “the computers are often unaccountable: an algorithm that rates teachers and schools, Uber drivers or businesses on Google’s search, will typically be commercially confidential. Whatever errors or preconceptions have been programmed into the algorithm from the start, it is safe from scrutiny: those errors and preconceptions will be hard to challenge” (Harford, 2016).

Given the power that future computer scientists are likely to have, as suggested by Zook and Graham, I believe, in line with Mitchell (1980) and the IFTF report, that it is imperative that all students, those who will become Computer specialists, and those who will be privileged and marginalized by what the Computer specialists create, also develop the broader ways of thinking outlined by the digital maker discourse. But given Chan et als findings, and Turkle and Papert’s work, which both suggest the pedagogy technical students are exposed to can encourage a mindset that stifles criticality, given the apparent failure of Logo to develop a generation of epistemologists, given the frictions between computational and critical ways of thinking, is this a pedagogical antithesis or is it possible for Computing teachers to incorporate both into their pedagogical landscapes? How might this be possible when teachers are working with a curriculum which has disaggregated the subject even further, and where literacy has been demoted to a functional skill? As knowledge, or our perceptions of it, are changing, are the theories of learning underpinning Computing education, the language used to talk about learning, guiding educators towards learning design which will support learners in managing these new knowledge forms, or simply continuing to reinforce a conservative educational agenda? The next two chapters will explore the language used in the literature around computational thinking, digital literacy and critical thinking.

Chapter 2 – Computational Thinking in the literature

"… in order to draw a limit to thinking we should have to be able to think both sides of this limit (we should therefore have to be able to think what cannot be thought). The limit can, therefore, only be drawn in language and what lies on the other side of the limit will simply be nonsense" (Wittgenstein, Tractatus Logico-Philosophicus)

Introduction

In the previous chapter I have explored the current context in UK Computing education and argued that through the debasement of digital literacy to meet a political agenda, the aims of the digital maker discourse and ideas around creativity and criticality, which are vital in Computing education, are in danger of being sidelined in favour of a deterministic view of 'computational thinking'. In this chapter I will explore some of the literature on 'computational thinking' which takes this latter approach and that has been influential in the UK context, and set this against broader literature that positions the notion of computational thinking more in line with Papert's epistemological pluralism and as an abstract/concrete bridge.

I will begin by reviewing some of the literature around computational thinking that has been influential within the Computing national subject association, and more widely, in terms of defining this term for educational purposes, to begin exploring what is computational thinking and what is the purpose in teaching it: what is its relevance to IT and/or digital literacy, as well as CS? The starting point is a literature review undertaken by Selby (2013) that attempts to produce a definition of computational thinking, the results of which were then used in nationally provided teacher training. I will discuss the limitations of these and similar definitions and the discourses that they reinforce, particularly in terms of the importance of digital or computational literacies. I will revisit the literature selected by Selby with an alternative agenda: to explore how they reinforce or refute the themes in the discourse promoted by the SDR report and I will show that there is a broader perspective to be found within this literature, particularly that coming from the U.S.. Finally, I will describe the framework for computational thinking presented within the same time frame by the successors of Logo, the ScratchEd team, which also takes a broader view.

2.1. Concepts of computational thinking

Following the release of the SDR report, the debates around coding for all or coding as a specialism continued. CAS made a significant amount of CPD available to teachers over the following years through their Network of Excellence and Master Teacher programmes, and continues to do so at the time of writing. The training provided to teachers by CAS had computational thinking at its core, and the definition of this concept was largely based on a literature review by Selby (2013). Selby discusses the debate around whether a consistent definition of 'computational thinking' is necessary or of value for Computing education, and believes that "The balance of argument is still in favor of searching for a robust definition" (ibid, p.2), for curriculum design and assessment purposes, the main argument being, rightly, that with our current mechanisms it would be difficult to assess something we can't define. The resulting definition found a strong enough foothold very quickly to underpin the CAS training for Master teachers in the following academic year, and the associated assessment framework for schools called Computing Progression Pathways (see for example http://academy.bcs.org/CTframework). This provided some much needed clarity for teachers at a time when the existing assessment levels were removed in all subjects as part of the national curriculum review. However the implications of seeking such a definition perpetuates a theoretical division that Papert's work was attempting to transcend, and so it is this aspect of the work that this section focuses on.

Selby's literature review begins with Jeanette Wing's 2006 definition of the term (discussed further below). This latter definition Selby suggests is too broad, but despite this perceived limitation, Selby's review was based on a search for literature that referred directly to Wing's definition as a starting point. Of twenty-two documents examined in the review, there were only fourteen different authors, and from this work, Selby aimed to investigate candidate terms for inclusion in the computational thinking framework for use in education.

An initial difficulty in attempting such a definition is evident in use of terms around 'concepts' and 'abstraction'. The first term included is "the concept of a thought process" (ibid, p.2). Defining "Computational thinking" as a thought process seems to be rather self-referential and therefore I would question the usefulness of this for the desired outcomes of a definition. Additionally, "…a definition of computational thinking should include the concept of abstraction" (ibid, p.2). The problem beginning to appear here is that terms such as 'concept' are being used without that notion itself being fully unpacked, as 'concept' creation itself is inherently tied to the process of abstraction (see Blunden, 2011). The result is that the attempts to define a term such as "computational thinking" are impeded from the start, when the focus is on defining the "computational" before the notion of "thinking" is clearly operationalized.

Defining a thinking skill in this way, for educational purposes, is problematic, yet this is in the end what Selby explicitly claims the resulting definition has done:

> "The description, as proposed above, narrows the definition by excluding some proposed terms. It separates the practice of skills from the thinking. It separates the results or evidence of the application of skills from the activity of thinking" (Selby, 2013, p.5.).

Clearly the argument is given that such an abstraction is needed to enable assessment, but I will argue that these particular abstractions, based on the theory/practice divide, are reinforcing the hegemony of the abstract, and that a social theory of learning can instead provide a more ethical, yet still operational, alternative.

What is particularly frustrating about this approach is that, again, it denies the potential pluralism inherent within Computing, with the possibilities Papert highlighted for Computing education to act as a bridge transcending this dualism. In contrast, the digital maker discourse promotes the computer-as-bridge perspective. Similar perspectives to the maker view are actually quite prevalent in the literature selected by Selby, and in the next section I will revisit this literature and show that while there is still considerable entrenching of the knowledge/action dualism, there is also much that moves the discourse towards the computer as “betwixt and between the world of formal systems and physical things; … [with] the ability to make the abstract concrete” (Turkle and Papert,1990, p.2).

2.2. Computational thinking in the literature: an alternative exploration

In her 2006 article, Wing positions the process of abstraction as the “most important and high-level thought process in computational thinking”. Immediately the hierarchy of thought is present, with ‘high-level’ thought, situating more abstract thought as ‘higher’. Hu (2011, p.225) also reinforces this hierarchy, giving a mathematical, abstract example to justify his view that: “A way of thinking at a higher order generally requires systematic training in a relevant field”. Having said that, he then describes how the mathematical example (Schwarz-Christoffel conformal mapping and computing the mapping function), only became successful in 1980s. Ontologically, this situates mathematics as an evolving knowledge base, in contradiction to the notion of ‘a right way’ to do things.

Many of Wing’s examples of what constitutes computational thinking are about dealing with uncertainty through reductionism: “It is separation of concerns. It is choosing an appropriate representation for a problem or modelling the relevant aspects of a problem to make it tractable”, and explicitly, “It is planning, learning, and scheduling in the presence of uncertainty” (Wing, 2006, p.34). The CAS curriculum (2012) takes a similar view of abstraction. In this document, the authors claim that, “Understanding this complexity and bringing it under control is the central challenge of our discipline” (ibid, p.4) and “Abstraction is both presenting a simplified version through information hiding and making an analysis to identify the essence or essential features” (ibid, p.7). They recognise the difficulties in this process through the use of parentheses in the following comment: “Scientists, industrialists, engineers, and business people all use computers to simulate and model the real world, by abstracting away unnecessary detail and using a computer program to simulate (what they hope is) the essence of the problem” (ibid, p.8).

Wing also recognises the reductionist nature of this process: “In working with rich abstractions, defining the ‘right’ abstraction is critical. The abstraction process—deciding what details we need to highlight and what details we can ignore—underlies computational thinking” (Wing, 2008, p.3718). She parallels this process of abstraction for computational means in the search for Computing pedagogies: she asks in what order should we teach concepts, how do we use computers to teach them and ensure the underlying concepts are understood rather than just use of the tool, and then she explains, “These questions are analogous to choosing the right abstraction where now the criteria are defined by learning ability” (ibid, p.3721). Deciding what details can be ignored is arguably more fraught with ethical issues for a social enterprise such as education, for designing pedagogy, than for mechanising a computable process. The danger is, as Winther suggests:

> “According to these two pragmatists, [James and Dewey], whenever context is ignored, abstractions become what will be here called “pernicious reifications.” That is, whenever one forgets (i) the particular function, (ii) the historical conditions of emergence, and/or (iii) the appropriate analytical level of an abstraction, the products and processes of abstraction become inappropriately universalized, narrowed, and/or ontologized” (Winther, 2014, p.1).

In terms of the ethics of the abstraction process, in the National Research Council (2010) report on the scope and nature of computational thinking, a number of participants had contributions to make. Andrea diSessa “argued that abstractions must be paired with grounding if people are to understand the significance of those abstractions. In diSessa’s words, “Abstraction has to connect with their concerns, whether they are menial or whether they are grand. It has to be grounded in people’s beliefs and feelings some way or other””(ibid, p.17). The same report also quotes Ashley as expressing:

> “a caution that computational thinking might lead to over-mechanization of complex processes. “Legal problem solving is highly context-dependent in ways that may not be anticipated. … We don’t want mechanical jurisprudence here. I think this caution probably applies in a lot of other areas as well”” (ibid, p.38).

From exploring the same literature as Selby, I would suggest that although abstraction is considered by most to be central to the subject of Computing, there does not seem to be clear agreement about how to define that term even purely for purposes of the discipline, and it is certainly a contentious term with ethical implications for subject pedagogies. The points raised in the literature around these ethical considerations, highlight the perspective Papert took in viewing computational thinking as a way to teach children “that there is such a thing as a "style of thinking"” (Papert, 1980, p.27), and that each has limits.

2.3. Computing as the abstract-practice bridge

Several of the selected authors do strongly connect practice with knowledge in Computing. Hu (2011, p.227) points out that, “Doing influences the way we think. A thinking paradigm means little to virtually anyone who hasn’t had much experience in doing things with which the paradigm may help”. Denning describes his work on defining principles for the subject, which he describes as:

> “… guidelines for conduct. Practices are the actual, embodied skilful routines and habits by which we take action. You can have levels of skill in your practices, such as beginner, competent, or expert. Knowledge of the principles does not imply you can perform competently, any more than competence in action implies you can discuss the principles intelligently. … To be a complete computing professional, you should know the principles and be competent in the four practices” (Ubiquity, 2007).

This emphasis on the indivisibility of competent practice and knowledge is important and at odds with the desire to separate thought and practice for educational measurement. The Computer Science Teachers Association (CSTA, 2011) report parallels the creativity of Computing with practical activities more traditionally associated with creativity, and uses this as a justification for the 'coding for all' agenda:

> "… hands-on experience adds immensely to life-long appreciation and understanding, even if the student does not continue programming, playing, or painting as an adult. Although becoming an expert programmer, violinist, or oil painter demands much time and talent, we still want to expose every student to the joys of being creative. The goal for teaching CS should be to get as many students as possible enthusiastically engaged with every assignment" (CSTA, 2011, p.5).

L'heureux, Boisvert, Cohen and Sanghera (2012) is another paper referred to in the Selby review that has a purpose in opposition to an agenda aiming to divide thought and practice. L'heureux et al explicitly try to ground abstract notions in practice, through teaching computational thinking within IT teaching, with a problem based approach:

> "While numerous variations of CS Principles courses have been created and offered as pilots across the country, all have been developed using traditional CS constructs. There is a significant need to expand that process to a more broad-based computing approach while maintaining the integrity of the underlying constructs. IT Problem Solving takes a more novel and applied approach to achieve a comparable outcome" (ibid, p.6).

In opposition to Selby's aim towards a definition of computational thinking, some participants in the National Research Council report (2010) go so far as to suggest that the separation of thinking and practice is futile, and additionally relate this to Logo. These participants:

> *"…* argued that computational thinking is an emergent property of technological advance. As technologies develop they enable new forms of computational thinking. Others believed that the connections between information technology and computational thinking were so deep that it effectively makes no sense to regard the two as separate. In this view, the computer—and notions of computer programming—can make the concepts, principles, methods, models, and tools of computational thinking tangible, in much the same spirit that LOGO was first inspired" (ibid, p.61-62).

2.4. Computational thinking as 'natural'

Similarly to SDR, Wing's articles suggest an underlying deterministic view in her description of learning ability and mathematical abstractions as innate: *"*For example, what, if any, computational thinking concepts are as innate to human cognition as is the mathematical concept of numbers?" (Wing, 2008, p.3721). This view of learning ability as innate is problematic in educators, as suggested by Papert in his call for epistemological pluralism in allowing multiple 'ways in' to Computing, and also in Cutts, Cutts, Draper, Patrick and Peter (2010) work on encouraging "growth mindsets" in students of programming, where they claim:

> “77% of teaching staff polled disagreed with the statement “Nearly everyone is capable of succeeding in the CS curriculum if they work at it.” It is at least as important that teaching staff have a growth mindset as it is for their students” (2010, p.435).

This innate view of learning ability is also present in the National Research Council report, where Knuth even suggests there is such a thing as a natural computer scientist: “CS&E is a field that attracts a different kind of thinker. I believe that one who is a natural computer scientist thinks algorithmically” (National Research Council, 2010, p.48).

Guzdial in contrast, advocates Computing for all and in doing so promotes pluralistic approaches to teaching and situates computational thinking as a literacy: “Computing professionals and educators have the responsibility to make computation available to thinkers of all disciplines ... To teach computational thinking to everyone on campus may require different approaches than those we use when we can assume our students want to become computing professionals. … Research in computing education will pave the way to make “computational thinking” a 21st century literacy that we can share across the campus” (2008, p.25). The only reference in Selby (2013, p.9) to Guzdial’s (2008) paper is to claim it attempts to define computational thinking. I would argue that Guzdial does not do this at all, but instead claims that we need more CS educational research to explore how people might learn ideas of computation best, in order to develop languages and tools that support such learning, a very Papertian perspective.

2.5. Criticality

A number of authors in the literature selection highlight critical thinking, in a similar context to the empowerment discourse through the call for coding for all. Hu (2011) claims that, “… a person’s critical thinking ability is applicable in any problem-solving context”, and suggests that criticality ought to be our focus:

> “Computation is diverse. Thus, it is hardly possible to describe computational thinking to encompass all possible thinking modes, their combinations and derivatives … In the end, what matters is our ability to think critically, not the labelling of a thinking process” (ibid, p.226).

But Hu only then defines critical thinking through a list of eight thinking “traits” from the Foundation for Critical Thinking. He describes the process of critical thinking as bringing existing knowledge to bear on new problems in new domains and using it appropriately to solve a problem. Chapter 3 will explore the literature around “critical thinking” which suggests Hu’s definition is still very narrow.

The CAS curriculum also suggests students of CS will be proficient in: “thinking critically**,** reflecting on ones work and that of others, communicating effectively both orally and in writing, being a responsible user of computers, and contributing actively to society” (2012, p.9). In the National Research Council (2010) report, participants connected criticality with understanding the limits of abstraction, in the same way as the IFF report seen in the previous chapter, and thus connect criticality again with the ethical dimension of the term abstraction:

> “Yasmin Kafai noted an example of the importance of understanding models and their limitations: “Government authorities often use models to make predictions, but people often don’t understand how these models were made, what the parameters are, or what kind of assumptions are underlying them . . . citizens need to also understand how decisions are being made and what some of the pitfalls in the models will be.” Wilensky added that computational thinking involves more than using models, experimenting with models, or even constructing them; it also involves creating a culture of model critique” (ibid, p.44).

2.6. Scratch – an alternative perspective on computational thinking

The ScratchEd team developed a Computing curriculum and a framework for computational thinking that is very different to the one defined by Selby and subsequently used by CAS. The Scratch framework takes many of the above broader concerns into account, such as Computing as a bridge between the abstract and practical. It is useful to see how such a different framework looks, as this connects computational thinking more clearly to the digital maker discourse that will be explored in the next chapter.

The free programming language Scratch was developed to teach programming concepts through the creation of games and animations, with a drag and drop, block style programming environment. It is a descendant of the Logo project, in that it is a programming language designed to teach coding from a creative perspective. The project is based at the MIT Media lab, led by Mitch Resnick who studied under Papert, and has very similar aims to the Logo project, though appears more focused on teaching computational thinking for its own sake. A key component of the project is the web site on which users can share their projects, not just the final creations but the code also, such that it can be reused, and they can work collaboratively on projects with other learners around the world.

The ScratchEd team created a curriculum around their tool, which they called “Creative Computing”. A draft of this accompanying document was available publically in 2011, and a ‘final’ version was online in 2014. The versions of the document refer to different sets of standards, the draft using the ISTE (International Society for Technology in Education) 2007 standards and the final version using the Common Core standards (2010) for English Language Arts & Literacy in History/Social Studies, Science, and Technical Subjects. The changes indicate a shift away from individualised views of e-safety and digital/computational literacy towards the maker and participation discourse. The final 2014 *Creative Computing with Scratch* document (Brennan, Balch and Chung, 2014) connects the standards referred to with an explanation of how use of the Scratch tool can meet a particular standard:

> “They come to understand other perspectives and cultures. – In remixing others’ [Scratch] projects, students need to read, understand, and interpret the code and intention of work that is not their own. When building up collaborative projects, students learn to cooperate, compromise, and share work with others” (ibid, p.139).

Here, understanding code becomes a tool for critically reading the work of other coders, and there is an emphasis on difference and perspective which the framework goes on to take as central to learning Computing.

In the Creative Computing curriculum (ScratchEd Team MIT, 2014), the rationale for using the term ‘computational thinking’ and developing a framework for it is given as: “we have been captivated by “computational thinking” as a way to describe the learning and development that take place with Scratch”. In Brennan and Resnick (2012) the authors explain again that they are interested in the term both as a way to explore learning with Scratch, but also in how Scratch provides a context to add to the conversation around computational thinking. The fundamental ethos behind Scratch is design-based learning for computational thinking and the maker, or bricolage approach (see Turkle and Papert, 1990) of Papert’s constructionism. The connections with digital making are drawn strongly: “…[our] interest is rooted in a commitment to learning through design activities, a constructionist approach to learning that highlights the importance of young people engaging in the development of external artifacts” (Brennan and Resnick, 2012, p.3).

The Scratch definition is divided into three elements: concepts; practices; and perspectives. The practices consist of four main “sets” that were also observed in children using Scratch and these are: “being incremental and iterative, testing and debugging, reusing and remixing, and abstracting and modularizing” (ibid, p.7). The authors claim that with these computational practices the focus is “on the process of thinking and learning, moving beyond what you are learning to how you are learning” (ibid, p.7). The perspectives are: expressing; connecting; questioning. The justification for including this perspective element of the framework, which is entirely different to the majority of the discourse around a computational thinking definition explored above, is:

> “In our conversations with Scratchers, we heard young designers describe evolving understandings of themselves, their relationships to others, and the technological world around them. This was a surprising and fascinating dimension of participation with Scratch – a dimension not captured by our framing of concepts and practices. Thus, as the final step in articulating our computational thinking framework, we added the dimension of perspectives to describe the shifts in perspective that we observed in young people working with Scratch” (ibid, p.10).

In terms of assessing the development of computational thinking with this framework, three approaches are described: an automated tool that gave data on the use of Scratch blocks (which map to the list of concepts) within a project; artefact based interviews; and design scenarios. In reflecting on these approaches, Brennan and Resnick say:

> “None of the three approaches were particularly effective for *understanding changes in computational thinking perspectives* [my emphasis]. It is challenging to explicitly ask a Scratcher how participation in an activity like programming with Scratch has contributed to a shift in understanding oneself or the world” (ibid, p.22).

But they do consider how the evaluation of the young people's learning, even through interviews, in itself encourages a reflexive attitude: "Whatever the form, conversations about their work engage young people in a meta-cognitive activity, encouraging them to think about their thinking, a capacity important to developing as a self-regulating learner" (ibid, p.23). Finally, in the process of developing their framework, they note the limitations of a framework that is based on concepts only: "it was evident that framing computational thinking solely around concepts insufficiently represented other elements of designers' learning and participation" (ibid, p.6). The design of my research project centres around the notion of perspectives and suggests why this is indeed an important aspect of evaluating learning. The project applies a methodology for both exploring changes in perspective and encouraging pupils to think about their thinking.

2.7. Summary

There are many positive messages in the literature that are pushing the field towards a broader conception of what computational thinking might mean in educational terms. But these efforts are still undermined by language confusions. These difficulties with language reflect Dewey's (1896) philosophic fallacy: in brief, Dewey describes the classic reflex arc in psychology, the stimulus-response theory, through the example of a child reaching for a candle. Dewey explains how activity was at this time normally interpreted as a stimulus, such as the light of the candle, encouraging a response - the child reaching out to touch it. Similarly the sensation of the burn, is the stimulus to retract, the response. But Dewey suggests we could in fact say that the activity begins with a response, a motor-coordination, of the head, eye and muscles, moving such that the candle is in the field of vision, in a continuous transaction with the environment, "determining the quality of what is experienced" (ibid, p.358), and thus, "it is the movement that is primary, and the sensation that is secondary" (ibid, p.358). The language we use to categorise a moment of transaction within the environment, does just that – it defines a moment: any part of that transaction could be seen as at one time a stimulus, or at another a response, depending on our choice of terms to interpret it. But it is only the language that draws a boundary around the moment that reifies it, in order for us to make sense of it, rather than there being something essential of a particular term in that moment itself.

In the National Research Council (2010) report, Sussman explains how "Computational thinking is about how a group of people can cut and share an apple so that each person feels he or she got a fair share of the apple" (ibid, p.28), as opposed to mathematical thinking which would be about spheres and area volume dimension for example. So which 'kind' of thinking we are talking about depends on aims, on function: it is about taking a perspective depending on how the problem at hand is defined, and recognising the part language is playing in talking about a particular type of thinking in a particular way, as Dewey's philosophic fallacy suggests.

The National Research Council (2010) report claims that the ideas behind Logo were "quite similar to those underlying the advocacy of computational thinking" (ibid, p.46), but that the cultural context is now very different. I would argue from the literature explored above, there is a divide in what is being advocated for, and while the broader view has some similarities with Papert's aims, the academic focused computational thinking advocacy in the UK is in fact promoting the hegemony of the abstract in such a way that opposes Papert's aims.

We have seen that Logo did not fulfil its potential, partly due to technocentrism in the implementation and evaluation of its use, partly for broader cultural and political issues. But I will argue also because of the limitations of the constructionist view. This can be seen in how the antecedent work on Scratch is framed in the literature: despite the acknowledgement of perspectives as a crucial aspect of learning, computational thinking is still not positioned as one tool from a toolkit of ways to think, and so there is little discussion about what drives the process of selection of these thinking tools, critical evaluation of knowledge claims, and reflection on one's own approach. These are inherently issues of literacy, which the UK curriculum has instead demoted. We need to take the broader views of literacy and criticality into account, and the next chapter will explore the use of these terms in the literature in relation to how they can inform and be incorporated within Computing education.

Chapter 3 – Digital Literacy and Criticality

Once people have allowed themselves to become puppets, never questioning what they find themselves doing or why they are doing it, then they have arrived at a dangerously negligent level of intellectual abdication, and there are some very evil people poised to exploit that. (Brookmyre, A Snowball in Hell)

Introduction

In the previous chapter I argue that literature around computational thinking falls roughly into two camps: one promotes the hegemony of the abstract, academic, conceptual view; and the other promotes the indivisibility of Computing competence and knowledge, and situates computational thinking as just one tool from a toolkit of many ways of thinking, or as Papert would say, takes an epistemologically pluralistic approach. We have seen that critical thinking is raised in discussions of computational thinking but vaguely. Notions of literacy in the computational thinking literature range from the most basic of skills to a new way of thinking.

In this chapter I will explore the literature around notions of criticality and digital literacy, to consider how these relate to Computing education, asking how is digital literacy defined and operationalized and how does this relate to the digital maker movement, to the computational thinking discourse and to Papert's epistemological pluralism? Further, what purposes and pedagogies are privileged in the discourse around digital literacy and literacy more genrally, and how do these relate to notions of critical thinking within formal education?

Ultimately, the literature explored indicates that literacy and thinking are functionally one and the same, and a 'critical' positioning of both concepts is crucial for education. What does this mean for a curriculum that has manipulated these concepts to create a hierarchy from the 'higher' thinking to the 'basic' literacy? What is really meant by the term 'critical' and how can this be applied to a pedagogy of Computing, which we have seen in the previous chapter tends to a deterministic perspective? As I will show, recent literature around 'critical thinking' in particular, emphasises epistemic perspectives, and this would suggest Papert's project aims for "epistemological pluralism" were inherently moving towards criticality. But the literature around research into learners' 'epistemology' contends that this latter term and the subsequent work around it is also problematic.

Finally I will ask whether aiming to develop criticality in learners, is justifiable and achievable, particularly at high school level, with respect to Computing.

3.1. Digital literacy - definitions and themes in the literature

Traditional literacy is associated with basic reading and writing and Goodfellow claims this is still the case when he suggests, "Despite a growing tendency in general discussion for the term 'literacy' to be used synonymously with 'competence' or 'ability' (as in 'musical literacy', 'scientific literacy', 'emotional literacy' etc.), in everyday contexts it is still largely taken to mean the ability to read and write in a predominantly print context" (2011, p.1). But Warschauer explains that even the competency view is too narrow and that literacy is inherently political: "… being literate has always depended on mastering processes that are deemed valuable in particular societies, cultures, and contexts" (Warschauer 1998, p.1). Both these authors agree that notions of literacy have been challenged through technological change. This shift includes additional concepts such as digital literacy, media literacy, and multiliteracies and there is a large volume of literature around these ideas, which has been mostly ignored in the development of the Computing curriculum, as evidenced by the definition of digital literacy as a basic skill.

Two notions of literacy that are most explicitly connected with digital literacy are technological and media literacy. The US National Academy of Engineering produced a report and associated website as part of a two year study by the Committee for Technological Literacy. This report advanced a view of technological literacy that "encompasses three interdependent dimensions: knowledge, ways of thinking and acting, and capabilities", with the goal of providing people "with tools to participate intelligently and thoughtfully in the world around them" (National Academy of Engineering, 2002, p.3). The detail given for each dimension mirrors much of the skills listed by the IFTF report mentioned in chapter one, and there are parallels in the divisions made with the Scratch framework for computational thinking - concepts, perspectives and practices.

Media literacy is another competency area that receives attention. The Aspen Institute task force on learning and the Internet include media literacy in their notion of "digital age literacy" along with digital and social-emotional literacies. They describe media literacy as: "the ability to understand, interpret and use different forms of media: books, hypertext, videos, podcasts and much more." (Aspen Institute, p.72). In the research literature there is recognition that definitions of digital literacy are, " in flux as new forms of digital information and delivery emerge" (Hull, Mikulecky, St.Clair, Kerka, 2003, p.10). Definitions of digital literacy centre variously around the medium, specifically any digitised media, and competencies with technology. The medium focus is on the digital format but essentially the skills or qualities referred to are no different to broader notions of information literacy, such as ability to "access, judge and communicate" (Hull et al, 2003, p.13). In terms of competencies, the focus tends to be on eSafety issues (see for example Aspen institute, p.72) or searching and online techniques, but Greene, Yu and Copeland recommend extending even this skill based perspective to be "critically inclusive of searching, vetting and integrating information into the meaning-making process during online learning" (Greene, Yu and Copeland, 2014, p.6). A meaning-making view is also advocated by Goodfellow (2011, p.2): "… 'digital literacies' are not simply the skills involved in using digital communication, but the diverse ways of making meaning that involve 'digital encodification'".

The notion of information literacy appears to encompass the key ideas in the literature around competency literacies, such as scientific and digital literacies. It is empowering and "a fundamental human right" (Coonan, 2011, p.5) and "a key part of lifelong learning" (ibid, p.4). It is "a way of knowing and informed by the sayings, doings and relatings specific to the environment" (Lloyd, 2014, p.88). There appears to be a move here towards using the construct of information literacy as suggesting a way of learning, particularly related to ideas of self-directed learning as in Coonan (2011, p.4) who says that "autonomy is a significant element in definitions of IL [information literacy]". Greene et al even connect critical aspects of digital literacy to such purposes, arguing that their study "provides evidence that SRL [self-regulated learning] and EC [epistemic cognition] are relevant aspects of digital literacy" and thus they include these phenomena in their definition of digital literacy (Greene et al., 2014, p.25). The connection with self-directed learning and epistemic perspectives is echoed in the literature around critical thinking, which I will explore below.

3.1.1. Multiliteracies

The idea of multiliteracies advocates the contextual nature of competency definitions, suggesting the importance of working across competencies. Goodfellow (2011, p.2) believes that "contexts of communication practice in the modern world are now so diverse, and the media of communication so multimodal, that it is not useful to think of literacy education solely in terms of developing generic competences that can be transferred from context to context". Likewise Coonan warns that separating literacy as generic skills rather than core to the practice of a discipline:

> "…allows its advocates to champion its importance, but its forcible disconnection from the academic curriculum undermines any status it may achieve through advocacy" (Coonan, 2011, p.8).

Kalantzis, Cope, Chan and Dalley-Trim suggest that a multiliteracies approach that emphasises the contextual aspects of literacy, and that focuses on being literate in multiple contexts, underlies the critical project of literacy: "An ability to work across literacies in the plural opens paths to social participation" (2016, p.7). They situate literacy teaching as:

> "… creating a kind of person, an active designer of meaning, with a sensibility open to differences, problem-solving, change and innovation. The logic of Multiliteracies recognises that meaning-making is an active, transformative process. A pedagogy based on that recognition is more appropriate for today's world of change and diversity" (ibid, p.226).

A critical perspective of literacy is at the heart of Freire's work and related literature taking a political stance, which focuses on empowerment and enabling action for social good, but also with meaning-making as central to the framework. In Freire's terms, literacy itself is only:

> "… a meaningful construct to the degree that it is viewed as a set of practices that functions to either empower or disempower people. In the larger sense, literacy is analyzed according to whether it serves to reproduce existing social formations or serves as a set of cultural practices that promotes democratic and emancipatory change … [it has to be] viewed as an integral part of the way in which people produce, transform, and reproduce meaning". (Freire and Macedo, 1987, p.xii).

Freire and Macedo describe how the theory/practice divide in approaches to literacy causes: a separation between methodology and ideology; a focus on technical and efficiency issues; and divides the act of reading from the "socio-political structures of a society". This in turn, "gives rise to an ideology of cultural reproduction, one that views readers as 'objects'. It is as though their conscious bodies were simply empty, waiting to be filled by that word from the teacher." (ibid, p.145)

The approaches to literacy that Freire and Macedo (1987, p145-149) describe stem from a class based divide in the historical rationales for literacy which in the academic approach, "served to legitimize a dual approach to reading: one level for the ruling class and another for the dispossessed majority". For the well-educated man of the elite classes, "reading is viewed as the acquisition of predefined forms of knowledge and is organized around the study of Latin and Greek and the mastery of the great classical works" whereas, "it would be unrealistic to expect the vast majority of society to meet such high standards, reading was redefined as the acquisition of reading skills, decoding skills, vocabulary development, and so on". Thus literacy "functions, in fact, to reproduce dominant values and meaning". This is mirrored in SDR in the assumption that the majority will be unable to master a certain level of competence in CS, and it is suitable only for those "with an aptitude for the subject" (Furber, 2012, p.6), thus the need for creating an alternative functional requirement of digital literacy. Freire and Macedo go on to describe the utilitarian, cognitive development and romantic approaches to literacy (1987, p.145-149). The cognitive approach, which he claims was highly influenced by both Dewey and Piaget (ibid, p.148), emphasises the construction of meaning but is still insufficient in that it ignores students' own cultural capital, "their life experience, history, and language". The underlying problem with all three approaches, according to Freire and Macedo, is that:

> "… they all ignore the role of language as a major force in the construction of human subjectivities. That is, they ignore the way language may either confirm or deny the life histories and experiences of the people who use it" (1987, p.149).

The importance of language in the construction of subjectivity, its importance in 'thought' as well as literacy, guides the methodological direction of this study and will be explored in chapters 4 and 5.

3.1.2. Literacy as thought and learning

Another dimension of literacy that is highlighted in the literature is that of literacy as a way of thinking. Kozulin explains that literacy "in its different forms constitutes one of the most powerful of psychological tools" (2003, p.16), and drawing in the notion of multiliteracies, suggests, "the formation of different literacies is intimately related to the appropriation of different psychological tools" (ibid, p.16). He relates the development of literacy to a Vygotskian perspective: "From a Vygotskian point of view the essence of cognitive education lies in providing students with new psychological tools that can shape either general or more domain-specific cognitive functions" (ibid, p.16). This view supports Papert's perspective that we have seen above, which situates computation as a new domain-specific tool for thought, the development of which would enable children to have a better understanding about their own thinking generally, in addition to enabling alternative ways to understand other domain-specific principles: in the Mindstorms example, those of mathematics.

Similarly Kalantzis et al (2016) talk of literacies as mapping to the concept of thinking, but they attempt to avoid a mind/body dualism by focusing on the meaning-making process and using a framework of representation and communication. Kalantzis et al explain that:

> “We use literacies to make meanings for ourselves – silently, as we talk to ourselves using the concepts that language provides us, as we formulate arguments in our heads, as we write notes, as we create mental images, as we conceive things in diagrams, as we make models. Nobody need ever hear or see what our representations are. However, we are nevertheless using literacies to think and to make meanings for ourselves, to make sense of our worlds” (ibid, p.6).

Kress similarly focuses on communication and representation in meaning-making, seeing a theory of communication as “essential as the frame and model of a (social semiotic) theory of education”, (Kress, 2013, p.122). But Kress, Jewitt, Ogborn and Tsatsarilis believe it is important to differentiate these constructs: “representation focuses on what the individual wishes to represent about the thing represented; communication focuses on how that is done in the environment of making that representation suitable for a specific other, a particular audience” (2001, p.4). They extend this framework to be a theory of learning, whereby in remaking “potential for self-representation… This, we believe, is the process which we describe as ‘learning’, though it is also the process whereby the individual constantly remakes her or himself “, (ibid, p.6). This equating of learning with remaking of self, with identity, is central to the social theory of learning I will introduce in chapter 5.

In terms of a computational literacy, which is explored in more detail below, the medium is again the focus for diSessa when we talk about literacy, specifically the medium of a computer: but it is a medium or tool for extending thought, as one of the concepts that language provides us with – computation – and as a way of making models. diSessa suggests how this medium provides and constrains tools for thought, based on different levels or systems that:

> “… have limits in what they allow us to think about. Associated with them are particular modes of mediated thought and connections to other subsystems. Written language, the prototype of literacy, has an alphabet, a lexicon, a grammar and a syntax, and above these technical levels are conventions of written discourse, genres and styles and so on” (diSessa, 2001, p.7).

diSessa crucially reinforces computation, as with all literacy, as dialectically mediating between thought and action, not just in using the medium of the computer to create an abstracted model of reality (such as a flight simulator) but in creating a virtual or digital reality from abstract models and ideas, or thought, (such as the patterns created through expressing geometrical ideas via Logo) and acting as an aid to thought in the process: “Systematic representational systems aid discovery because they convert abstract “intellectual” patterns into spatial visible ones” (ibid, p.17).

Kalantzis et al aim to shift the emphasis of literacy pedagogy from "stuff that happens to have found its way into children's heads… to epistemology, or the things they are able to do in the world in order to know" (2016, p.74). In their framework, "learning to mean" involves moving between these ways of knowing, which they describe as 'epistemic moves' (ibid, p.202), and they "recommend purposeful weaving between different epistemic moves for explicitly targeted outcomes", (ibid, p.202), emphasising an approach that begins with ways of knowing in order to 'learn to mean', rather than divisions based on a knowledge domain (scientific, technological), or on the function of the literacy approach (functional, critical). Literacy as such, for Kalantzis et al becomes a theory of learning in itself.

3.1.3. Critical Literacy Pedagogy

The themes that appear in the literature around definitions of and frameworks for literacy we have seen are: content or discipline related, in terms of competencies and multiliteracies; purpose based, such as functional or critical literacy; and those notions that attempt to transcend the form/function delineations and situate literacy across people-in-practice with a focus on meaning-making, developing 'kinds of people'.

Discussions around pedagogy and curriculum similarly fall into these groups, although Wesley White (2009, p.1) claims that generally, "Though much has been said about the importance of critical literacy, relatively little has been said about *what* it actually is, *how* to teach it, or *what to do* with the problems inherent in teaching it."

Wesley White claims that, teachers generally "adhere to scripted curricula, pacing guides and norm-referenced assessments, all of which are anathemas to critical literacy. Although curriculum and textbook publishers claim that their materials promote critical thinking (note that they seldom claim to promote critical literacy however), large-scale and packaged curricula dictate both how and what teachers can teach and what students can learn" (2009, p.2). Freire is also critical of texts prescribing "how to":

> "I once suggested to a group of U.S. students that they consider the following for their masters theses: how many texts were there in the United States in 1984, for instance, on how to make friends, get a good job, develop skills; that is, texts that primarily give recipes? These texts are explained in terms of the general context that generates them. There are many educators who welcome this type of text, which in essence contributes to further de-skilling. I refuse to write such texts, because my political convictions are opposed to the ideology that feeds such domestication of the mind" (1987, p.93).

Other problems Wesley White raises with the teaching of critical literacy are, "asking the blind to lead the blind" (2009, p.2), where teachers may not have been taught a critical approach themselves at school. How they are taught to teach can then reinforce an uncritical approach. He claims this problem is exacerbated by the lack of good examples outside of the education landscape, where our major media, “presents “news” as facts and themselves as unbiased” (ibid, p.2). Finally, he suggests we should question whether a critical literacy agenda might do more harm than good if taught badly (ibid, p.56).

The question of teachers themselves having a critical approach is also raised by Hull et al (2003, p.7) who say, “critical pedagogies must begin with changes in the educator, pedagogically and politically”. Even those teachers who might perceive themselves to have a critical approach may fall into the trap described by Moon in relation to critical thinking: “Ironically his teachers might not allow Jez the intellectual space in which to engage in critical thinking about critical thinking because – as an undergraduate – they will give him marks according to whether he has critically thought according to their own conception of the process” (Moon, 2008, p.37).

There are differing perspectives on how directed pedagogy for literacy needs to be. Kalantzis et al claim, “Children in school are not taught the language of science explicitly. But by being exposed to the language of science while doing science, they learn its literacies, and so learn the ways of thinking embedded in those literacies” (2016, p.454). But Kozulin’s (2003) Vygotskian perspective appears to contradict this view. Kozulin suggests that although there may be difficulties in teaching these concepts, they are not a naturally occurring phenonmenon and must be taught: “Beyond these primitive tools lie the vast areas of higher-order symbolic mediators including different signs, symbols, writing, formulae, and graphic organizers … The acquisition of symbolic relationships requires guided experience; it does not appear spontaneously” (2003, p.23-24). It is interesting to note another potential reason for the lack of impact of the Logo project here. Kozulin claims that:

> “Symbols may remain useless unless their meaning as cognitive tools is properly mediated to the child. The mere availability of signs or texts does not imply that they will be used by students as psychological tools. … Moreover, even literacy acquired in the nominally formal educational setting does not necessarily lead to the cognitive changes unless this literacy is mediated to a student as a cognitive tool” (ibid, p.24-25).

Unless the teachers “properly mediated” the new ways of thinking that use of Logo facilitated, there was no guarantee that the students would become cognisant that what they were doing would provide them with a new way of thinking. This can be seen in use of the Scratch tool, where it is perfectly possible for students to design and create fantastic animations without realising the computational concepts they are employing to do so. “If there is no intentionality of the teacher–mediator, psychological tools will not be appropriated by the students or will be perceived as another content item, rather than a tool. Sometimes, teachers fail to help students in identifying symbolic tools that are presented together with content material” (ibid, p.26).

This relates also to the competency approach to literacy, as Kozulin essentially supports the separation of pedagogy for content and pedagogy for ways of thinking (both within disciplines, rather than separation into domain specific and generic pedagogy). He claims, “content material has its own logic – mathematical, physical, literary, historical, and so on – that does not necessarily coincide with the logic of the enhancement of cognitive functions" (ibid, p.32). The appropriation of the latter "differs from the process of content learning" because, "content material often reproduces empirical realities with which students become acquainted in everyday life, [whereas] psychological tools can be acquired only in the course of special learning activities" (ibid p.25). He explains that higher psychological functions are developed through an "emphasis on process rather than product" (ibid, p.30).

Kalantzis et al highlight issues of agency in defining critical literacy, and similarly for pedagogy, they connect meaning and agency: "A pedagogy of Multiliteracies requires that we recognise the pivotal role of agency in the meaning-making process" (2016, p.226). They describe the implications for pedagogy stemming from the moral aspect of critical literacy: "the balance of agency shifts from the vertical model of teacher-to-student knowledge transmission in didactic pedagogy to a horizontal student-to-student model of collaboration in which knowledge is co-constructed in a community of learners. These are the conditions in which students will be able to use literacies to take greater control over their own lives" (ibid, p.198).

But some authors raise the moral question of whether criticality and agency ought to be encouraged and taught. Wesley White (2009) argues we should be aware that we are using students as "catalysts for social change", to expect them to critique the very system they are living within, "the tenets by which their own parents live and their cultures operate" and that this could lead to "students dissatisfied with the very society, schools, and culture(s) we are preparing them to join and parents dissatisfied with us" (2009, p.56). He claims that he does not mean to discourage the teaching of critical literacy but to show that, "the buzzword is itself loaded and often misunderstood. If we are to teach critical literacy to our students, we must come to this noble endeavour critically. In this sense, we must use the lens of critical literacy to examine critical literacy itself" (ibid, p.56). I will explore this ethical dimension again, in relation to critical thinking, below.

3.2. Critical thinking and criticality - definitions and themes in the literature

We saw in the previous chapter Hu's research suggesting that "In the end, what matters is our ability to think critically, not the labelling of a thinking process" (2011, p.226), but that this process was then narrowly defined as eight thinking traits which are summarised as "we think with a purpose, raise questions, and embody a viewpoint by making assumptions and inferences and by using information and concepts, leading to implications". These themes of teleology, questioning, perspective and consequences are echoed in the wider literature around critical thinking, but there are additional themes, which also resonate with the broader frames of literacy.

Previous research on critical thinking in a technology context has focused on computer conferencing, taking a snapshot of critical thinking skills, as defined by various models, during online conversations for a particular course (e.g. McLoughlin & Mynard, 2009; Bullen 1998; McLean, 2005; Garrison, Anderson & Archer, 2001). More recent research has also looked at the impact of ‘epistemological beliefs’ on critical thinking but not specifically in relation to technology.

Whether critical thinking is defined in terms of its ‘form’ or function, it is only useful as a construct for exploring learning design if made operational:

> “Any defensible conception must construe critical thinking in such a way as to capture most of what people have in mind when they claim that developing critical thinking is an important goal of education. That is to say, it must be true to the core meaning of the educators’ basic concept of critical thinking. Should it fail in this regard it is largely irrelevant to educators concerned with developing critical thinking” (Bailin, Case, Coombs, and Daniels, 1999).

In this section I will explore the literature around this construct in terms of what it is, how it is operationalized and hence how it relates to Computing education and to the construct of literacy.

3.2.1. Criticality: form, function, dimension and Computing

McLean (2005) and Garrison, Anderson and Archer (2001) suggest that both process and product of thinking need to be considered in any definition of critical thinking. Activities that are often associated with critical thinking definitions, such as problem-solving, may be done critically or uncritically, so quality is important (Bailin, Case, Coombs and Daniels, 1999). Bailin et al (1999) say lists of abilities and skills are simply descriptors rather than psychological processes that use of the term critical thinking implies, and instead use a model of intellectual resources, including habits of mind. This parallels Selby’s attempt to separate, “the results or evidence of the application of skills from the activity of thinking” (Selby, 2013, p.5), described in the previous chapter. Selby however does not extend her exploration to include dispositions, but we saw that the ScratchEd team did see the importance of including perspectives in their framework.

The breadth of definitions around critical thinking is arguably greater even than the critical literacy arena. Ennis (1996, 2003) is often quoted, who centres the term on the function of reflectively making a judgement or decision. Moon also sees the outcome of critical thinking as usually resulting “in something to do with making a judgement, or judgements”, (2008, p.26) and that it “has a sense of ‘a good thing to be able to do’ about it” (ibid, p.26). Moon suggests a framework that delineates the scope of the construct through “dimensions” of critical thinking: breadth; longitudinal; disciplinary pedagogy; disciplinary episteme; technical, skills/form-as-content based; activity/form-as-process based (ibid, p.37).

While skills and competency-based frames of critical thinking appear to be out of favour, the traditional connection between the construct of criticality and notions of logic and rationality is still prevalent. Logic is in many ways fundamental to Computing, and thus the connection between criticality and logic with respect to this discipline is perhaps more pertinent than for other subject areas. Moon (2008) describes the historical approach to critical thinking as being grounded in the notion of logic, of which there are many forms. In terms of criticality:

> "The application of logic was seen to maximize the 'objectivity' of critique and argument – a point about which we might disagree … Logic deals with the quality of the reasoning and the argument. In terms of the activities of critical thinking … logic largely focuses on the analysis of the arguments of others and the construction of argument – though often the assumption in some of the introductory texts is that the subject matter is represented by problems with some kind of 'correct answer' which will be detected through the appropriate techniques of logical analysis" (2008, p.38).

Goodfellow also connects a view of critical thinking to forming an "academic argument, satisfied simply by maintaining a disinterested stance and presenting evidence for more than one point of view", and sees this construct of critical as disempowering (2011, p.8). Moon points out that the implied end point of a 'correct' solution is something "which we would not normally call critical thinking", (2008, p.41). This echoes Coonan's criticism, with regard to literacies, of the "positivist 'one right answer' approach, which is fundamentally and damagingly at odds with the higher-order functions of information literacy and with the interrogative nature of the scholarly mission" (2011, p.22).

Turkle and Papert (1990) describe how the notion of logic has also been elevated above other forms of thought, but ought to be seen as simply one tool: ""Hard thinking" has been used to define logical thinking. And logical thinking has been given a privileged status that can be challenged only by developing a respectful understanding of other styles where logic is seen as a powerful instrument of thought but not as the "law of thought." In this view, "logic is on tap, not on top"" (ibid, p.5).

diSessa also situates not just logic as a tool but claims "all "purely" intellectual capability – habits of mind tuned to particular services in scientific inquiry – should count as tools" (2001, p.39). He discusses how use of the word 'logic' in more everyday contexts is confused with intuitive knowledge, the latter which, for diSessa is based on p-prims, phenomenological primitives (ibid, p.91). These develop through our experience of the world but can't be broken apart to explain why they work (ibid, p.91), and are not always correct in the situations to which we apply them. He gives the example of Ohm's p-prim: more effort begets more result or more resistance gets less result. diSessa explains the contrasting nature of these p-prims with logic, and thus the limitations of the latter and the reasons why they ought not to be confused:

> "A syllogism is powerful in that it is certain, but almost nothing about the physical or social world matches the conditions for certainty that all syllogisms need …Genuine logic is not rich, but *sparse* … the main part of logic is about as complicated as arithmetic with only two "numbers", true and false. … In coming to a new situation, you invoke your existing p-prims and adapt them to it… In contrast, logic doesn't suggest new logics. It doesn't wander and change gradually as you experience new situations … *P-prims* are *rich* and *diverse*; they constitute a fundamentally *fragmented* knowledge system. In contrast, logic is *sparse* and

> *homogenous* in the structure of situations with which it deals… Finally although logic and language can go hand in hand, p-prims don't connect very well with language. … Logic is *articulate*; p-prims are not" (ibid, p.96).

I will return to logic in the next chapter when exploring abstraction and related language issues in more detail, but from the literature, it seems that notions of logic, which underpin computation, are antithetical to broader notions of criticality.

3.2.2. Criticality and ways of knowing

Criticality is widely connected with metacognition, which could also be seen as core to Papert's project. It is often conflated with 'reflection', but as Moon suggests, this "might promote a view of 'looking back on something' more than critical thinking" (2008, p.25). Another distinction between the two terms, based on purpose is, "There is also a sense of direction to critical thinking – a sense that we have some defined reason for engaging in the process. This would often be in distinction to reflective learning, where a sense of open exploration is implied" (ibid, p.26).

Moon also connects the construct of metacognition to epistemic views: "Metacognition is common to both reflection and critical thinking and, in particular, it seems that the development of effective reflection and effective critical thinking are both contingent on the progression of the learner away from an absolutist position and towards contextual knowing" (2008, p.129). She claims "critical thinking is not possible for those whose thinking is absolutist or dualist ('if something is right, it is just right and there is no justification needed'). Similarly, 'evidence is evidence and there is no need for evaluation of it'" (ibid, p.111). This supports the work discussed in the previous chapter by Bullen (1998) and Chan, Ho and Ku, (2011) which suggested that engineering students who are taught a correct way to do things may have a reduced capacity for critical thinking. Although as Moon suggests, this could be based on other factors also, because although "humanities students were less likely to have naïve views about knowledge as composed of 'definitive and absolute facts' … there are many variables in how a subject is taught … that make these generalizations about discipline and epistemological development difficult" (Moon, 2008, p.106).

Regardless of discipline, ways of thinking about knowledge do appear to be relevant to criticality. Moon lists a number of "continua" for the construct of epistemological beliefs: the certainty of knowledge - absolute or evolving; the organisation of knowledge – compartmentalized or integrated and interwoven; control of learning and speed of learning (ibid, p.104), and these variations in the term suggest issues with operationalizing it. Greene, Azevedo and Torney-Purta (2008) agree that the research suggests those with "less sophisticated views, such as the idea that history is objective, are ill-prepared for advanced academic work and lack the skills to think in complex and critical ways" (ibid, p.143), but they question use of the terms using "epistemology" to capture the real problem. They raise awareness of an important confusion caused by the use of language. Firstly they explain, if we use the term literally, epistemology refers to the study of knowledge, not the essential nature of knowledge, so ‘epistemological pluralism’ for example, would actually refer to multiple ways of studying knowledge, and thus ‘epistemic pluralism’ might better convey the aims of Papert’s project.

Greene et al disagree that views on control of learning, such as self-directed learning, should be included in study of epistemic beliefs: “including the nature of learning factors under the umbrella of personal epistemology is confusing the issue, and hampering an understanding of both” (ibid, p.149). Instead they suggest that with academic domains, researchers referring to knowledge beliefs are actually discussing a person’s ontology, which may be simple or complex (ontological development through study of history for example, from one of all history is facts, to differentiation of facts and interpretations). In discussing students with less sophisticated views, researchers are actually referring to:

> “… simplistic ontology with limited or unhelpful categories. When they discuss certain knowledge, they are referring to a specific attribute of different categories (i.e., knowledge claims within some categories are relatively static; claims in other categories have the attribute of potentially changing over time) … a person must have a sophisticated ontology of a domain before epistemic cognition and issues of justification become relevant at all” (ibid, p.150).

They claim that this supports the idea that knowledge beliefs are domain-specific and that “individuals’ epistemic and ontological cognition can vary across domains", which is perhaps inevitable given the different structure of the domains, for example: “math (a well-structured domain) and history (an ill-structured domain)” (ibid, p.154). Moon, still using the term “epistemological beliefs”, but referring to the same function, also puts forward the suggestion that there may be a difference in these beliefs with regard to spontaneous, or everyday, and scientific concepts, that they “may be more advanced in relation to everyday issues than in academic material” (2008, p.144). I will come back to this separation of everyday and scientific concepts in the next chapter.

3.2.3 Criticality and efficacy

Views on the nature of learning are important in both literacy and critical thinking. diSessa highlights the difficulties with a view of learning as predetermined, which resonates with the SDR view that only some children will have an aptitude for CS:

> “The conventional wisdom is that *only some* children and teachers can be intelligent and creative. For the rest we need to dumb down the curriculum and make it teacher proof. Perhaps the problem lies in the different orientation toward people rather than in the idea of computational literacies in general. A positive view of intellectual possibilities is indispensable, however” (diSessa, 2001, p.230).

Views on the nature of learning and intellectual possibilities are the focus of another construct in the critical thinking literature: efficacy beliefs. Efficacy beliefs and agency are central to Bandura's Social Cognitive theory, and this is how he frames issues around control of learning. He critiques a deterministic view of learning where:

> "The divestitive line of thinking is fuelled by conceptual reductionism, nature-nurture analytic dualism, and one-sided evolutionism. As previously noted, mental events are brain activities, but physicality does not imply reduction of psychology to biology. Knowing how the biological machinery works tells one little about how to orchestrate that machinery for diverse purposes" (Bandura, 2001, p.19).

Bandura emphasises the plasticity of the brain and describes how research has shown that not just exposure to stimulation, but "agentic action in exploring, manipulating, and influencing the environment" actually plays a role in shaping "the neuronal and functional structure of the brain (ibid, p.4)". Bandura critiques computational paradigms of mind which reduce consciousness "to a nonfunctional by-product of the output of a mental process realized mechanically at nonconscious lower levels" (ibid, p.3), where the view is that "people do not act on beliefs, goals, aspirations, and expectations. Rather, activation of their network structure at a sub-personal level makes them do things" (ibid, p.3). He suggests instead that cognitive processes are emergent and "Emergent properties differ qualitatively from their constituent elements and therefore are not reducible to them" (ibid, p.4).

For Bandura "Efficacy beliefs are the foundation of human agency. Unless people believe they can produce desired results and forestall detrimental ones by their actions, they have little incentive to act or to persevere in the face of difficulties" (ibid, p.10). He suggests this notion is becoming more important as the "rapid pace of informational, social, and technological change is placing a premium on personal efficacy for self-development and self-renewal throughout the life course" (ibid, p.11). He connects the power of efficacy beliefs with Freire's criticality project for social transformation and gives the example of Gandhi, who through "an unwavering exercise of commanding self-efficacy, mobilized a massive collective force … a high sense of efficacy promotes a pro social orientation characterized by cooperativeness, helpfulness, and sharing, with a vested interest in each other's welfare", (ibid, p.15).

If self-efficacy beliefs around learning are low it can have a significant impact, and this is particularly important for Computing pedagogy, where the process of programming inherently entails failure: "if they construe their failures as presenting surmountable challenges they redouble their efforts, but they drive themselves to despondency if they read their failures as indicants of personal deficiencies" (ibid, p.5). Efficacy beliefs are not purely individual in Bandura's theory and we again face similar questions about the ethics of teaching criticality, as discussed earlier in relation to pedagogical issues for literacy. Bandura's modes of agency include personal; proxy; and collective. In relation personal agency, Bandura claims that:

> "Personal control is neither an inherent drive nor universally desired, as is commonly claimed. There is an onerous side to direct personal control that can dull the appetite for it. The exercise of effective control requires mastery of knowledge and skills attainable only through long hours of arduous work. Moreover, maintaining proficiency under the ever-changing conditions of life demands continued investment of time, effort, and resources in self-renewal" (ibid, p.13).

Proxy agency is the way people manage the fact that it is not possible to "master every realm of everyday life" (ibid, p.13), and thus "people try by one means or another to get those who have access to resources or expertise or who wield influence and power to act at their behest to secure the outcomes they desire" (ibid, p.13). This can both promote and hinder self-development and "part of the price of proxy agency is a vulnerable security that rests on the competence, power, and favors of others" (ibid, p.13).

Perceived collective efficacy is an emergent property of "people acting conjointly on a shared belief, not a disembodied group mind that is doing the cognizing, aspiring, motivating, and regulating" (ibid, p.14). Bandura suggests beliefs of collective efficacy are also becoming more pertinent in current times and are directly related to understandings of technology: "As the need for efficacious collective civic action grows, so does the sense of collective powerlessness … Everyday life is increasingly regulated by complex technologies that most people neither understand nor believe they can do much to influence. The very technologies they create to control their life environment paradoxically can become a constraining force that, in turn, controls how they think and behave" (ibid, p.17). I will return to these ideas of efficacy in discussing the ethics of pedagogy for criticality.

3.3. Critical thinking and literacy

There are a number of areas where the constructs of literacy and critical thinking overlap in the literature. Hull et al (2003) suggest that critical literacy has a much broader scope than critical thinking and "includes not only learning to read and write in a technical sense, or the ability to think abstractly or to reason, but learning as well to take a critical stance toward one's historical, economic, ethnic, racial, and gendered positioning" (ibid, p.4). According to Moon, "the activity of critical thinking is seen as a disposition or stance towards the world" (2008, p.33). Perspectives then are central to criticality as Brennan and Resnick say they are to learning computation.

Kalantzis et al suggest, "Thinking and literacies are inseparable. Adult humans think through the representational systems that are literacies. Without these systems they could not think, or at least they could not think in the ways that are characteristically human" (2016, p.430). They situate literacy as a process concerned with constructing our selves, or becoming a 'kind of person'. Similarly in the field of critical thinking, Moon suggests "The state of self-authorship could be said, therefore, to lie at the heart of proper or good critical thinking … there could be a situation in which a learner, though fully understanding that she has constructed her own knowledge and is fully conversant with the processes of critical thinking, is too unsure of her social position in a particular context to express her ideas, and hence remains silent. She lacks academic assertiveness – and no one would know about the level of her critical thinking because it is unexpressed" (2008, p.88). Notions of expression and expressibility are important and yet underplayed in much of the literature around both constructs. Expressibility is an essential part of the theory I will explore in later chapters. Kalantzis et al do emphasise the importance of communicating meanings. They explain:

> "…this process of representation … allow[s] us to make meaning for ourselves. Literacies are tools for representing that meaning to others. Representation is the cognitive work that individuals do with their minds. It is the raw material of thinking" (2016, p.216).

We saw in the previous section that the literature advocating broader perspectives on literacy situate it as thinking or as psychological tools. Jonassen (1998, p.13), like diSessa, suggests that computers can be an extension to thinking and thus to literacy. There is an assumption that use of computers can thus engage criticality, but there is still no clear explanation of how this is so, especially given the range of constructs that we have seen fall under the umbrella of critical thinking. I will now turn to literature specifically on computational literacy to see if this answers the question.

3.4. Computational literacy

Kellner (2001, p.73) suggests that the concept of computer literacy should be expanded to involve "learning where information is found, how to access it, and how to organize, interpret, and evaluate the information that one seeks" which still situates it very much within notions of information literacy. The positioning of digital literacy within the SDR report is even more limited than this and would be within the functional literacy paradigm according to Warschauer, where "the computer becomes a vehicle for literacy (albeit of a limited scope) but does not itself become a medium of literacy practices" (1998, p.16). Jonassen gives examples of "semantic organisation tools" (1998, p.1) such as databases, concept maps, microworlds and modelling through spreadsheets and visualization, all tools which do represent knowledge in particular structures appropriate for computation, but which are not extending thought in the way Papert aimed for, not developing meta-cognition, or explicitly raising awareness of the ways in which one can think.

diSessa's Boxer project also aimed to view computational possibilities for a new literacy, for new ways of thinking. He uses the term computational literacy, rather than computer literacy to shift away from the focus on basic use of a computer implied by the latter term:

> "Clearly, by computational literacy I do not mean a casual familiarity with a machine that computes. In retrospect, I find it remarkable that society has allowed such a shameful debasing of the term literacy in its conventional use in connection with computers … as if a casual familiarity with any chunk of hardware that in any sense computes might do for humankind something comparable to what the written word has done" (2001, p.5 and p109).

He suggests that the “development of a computational basis for new literacies is orthogonal if not antithetical to most current trends” (ibid, p.28). As literacy “involves external materially based designs, symbols, depictions or representations” it inherently includes numbers as part of representation, and he uses this to relate programming languages to the construct of literacy (ibid, p.32) where programming is a kind of language that is apt for expressing ideas of motion, but not poetry for example. He positions programming languages as a new representational form for a new literacy that can mediate the way in which one learns new concepts.

This is supported by Bezemer, Diamantopoulou, Jewitt, Kress and Maversn (2012) who describe research into learning in a school, hospital and museum, using a multimodal approach to explain that writing and speech might be optimal forms of expression for scientific ideas such as digestion, but notions of force may be better represented by gesture, in the case given, the physical manipulation of magnets. The implications of this for pedagogy are that, “the role of the teacher, far from being ‘de-professionalized’, is becoming one of the teacher as rhetor and designer of different sites as maximally effective environments for learning” (2012, p.12). But this is problematized by the fact that assessment mechanisms determine what is legitimate as a sign of learning, and may not recognise all modes.

3.5. The problem with a construct of “digital literacy”

In Weinberger’s explanation of how computational forms are changing the way in which we understand and use knowledge, it is the release from reliance on the medium of paper that is driving the changes: “Transform the medium by which we develop, preserve, and communicate knowledge, and we transform knowledge” (2014, p.ix). Learning to evaluate knowledge claims is increasingly important and Weinberger warns:

> “… we need those critical-thinking skills more than ever. The Internet pioneer Howard Rheingold talks about these as "literacies." For example, we need to get better at distinguishing lying crap from well-documented conclusions, becoming more open to new ideas, and learning how to participate in a multi-way, multi-cultural discussion” (ibid, p.200).

Emphasising the influence of medium, Weinberger suggested that private thought is given elevated status, because the “physics of books generally makes writing them a solo project” (ibid, p.117). He explains the difference between a citation or reference, which is given as a justification for a claim, and a hyperlink, which tends to be towards an elaboration or contradiction, “a visible manifestation of the author giving up any claim to completeness or even sufficiency; links invite the reader to browse the network in which the work is enmeshed, an acknowledgment that thinking is something that we do together” (ibid, p.127).

The need for criticality is evident, as is the need for understanding ways in which networked knowledge can be organised through computational literacy, tools such as linked data and namespaces, the latter which Weinberger claims emphasises the sharing of data rather than how it is categorised and named: “you organize your data one way, I'll organize it another, namespaces and data model translators will let us benefit from each other's research, and we'll still be able to learn from one another's research. This is pragmatism not only in the usual sense of the term but also in the philosophical sense, as espoused by William James, John Dewey, and Richard Rorty” (ibid, p.159).

But there is no suggestion of how existing pedagogy in formal education can respond to this new shape of knowledge, whether broader perspectives on literacy and critical thinking are helpful, when they have both expanded from a foundation of skills based definitions, based on the ‘old’ hierarchical shape of knowledge. Weinberger outlines the central tenets of postmodernism (ibid, p.104-105) and claims the Net shows us, through the ideas described above, that these were ‘right’: all knowledge and experience is an interpretation; interpretations are social; there are no privileged positions; interpretations appear in discourses; within a discourse some interpretations are privileged. From the literature around critical thinking and literacies it can be seen that authors have tried to encapsulate these issues in the definitions they use. But in doing so, the definitions have perhaps become unwieldy and difficult to differentiate and operationalize. Literacy is defined as thinking itself, and also as a theory of learning. But this is so far removed from use of the term by SDR and in the curriculum that I would argue it has become unhelpful to use the same term. Papert recognised the contentions around use of the word literacy as related to the representational mediums we use, but was optimistic that technology developments will render these contentions irrelevant: “The use of the same word to mean both the mechanical ability to read as well as a rich connection with culture is one more reflection of today's paucity of media. As we enter an age in which diversity of media will allow individuals to choose their own routes to literacy, that dual meaning will pass away” (Papert, 1993b, p.2).

Others also question the usefulness of the term ‘digital’ when associated with ‘literacy’. Hull et al (2003) place meaning as central to literacy and raise the question of whether we should refer to this as ‘digital’ literacy at all: “Understanding, meaning and context must be central to it. It is not of importance whether this is called information literacy, digital literacy, or simply literacy for an information age”. This is reinforced by Eshet-Alkalai’s work on a skills-based theoretical framework for digital literacy, developed to be a “… diagnostic and evaluative tool” (Eshet, 2012 p.272). This framework consists of the following categories of digital skills: photo-visual; reproduction; branching; information; socio-emotional; and real-time thinking (ibid, p.268 – p.272). Eshet-Alkalai and Soffer acknowledge that digital literacy is not simply competencies of information seeking but “also relates to a variety of epistemological and ethical issues” (Eshet-Alkalai and Soffer’s 2012, p.1). Eshet-Alkalai and Chajut (2010) research whether age or experience are factors in developing digital literacy, as defined by this framework. They set tasks to explore these skills: photo-visual (understanding a graphic user interface); branching (navigating web pages reproduction); reproduction (rearranging a piece of text to assign new meaning) and information skills (writing a critical report). The former two, which specifically refer to technical use of a computer, are classed as “experience and technical control” (ibid, p.178) tasks, and the latter two categories as “creativity and critical thinking” (ibid, p.178). As is evident from the tasks set to explore these latter aspects, there is nothing inherently ‘digital’ about these skills. The findings suggest that younger participants initially perform better in “experience and technical control” (ibid, p.178) tasks, i.e. the inherently digital skills, but older participants improve in these through use over time, whereas the younger participants performance in “creativity and critical thinking” (ibid, p.178) decreased significantly over time and slightly improved for older participants. This leaves us with the problem that even when separating digital skills from a critical approach shows us the impact age and experience have on both, this doesn’t help us reunite these together in pedagogy to ensure the positive development of both, and still leaves us with a confusing picture of what is meant by ‘critical’.

3.6. The ethics of criticality

Zuckerman warns that we should be cautious in advocating a critical pedagogy: “Developing reflection is as dangerous as experimenting in nuclear physics and genetic engineering, with an outcome just as uncertain … To develop reflection in children or not? If yes, to what extent, and how to determine the critical permissible level?” (2003, p.195). These issues are extended by Bandura’s work, which we saw earlier, in the burden of personal agency, and the need for proxy agency. The perspective of literacy as necessary for social transformation perhaps assumes that all want that transformation, whereas Bandura’s theory would suggest that motivation is a crucial factor and even with a transformative education such as Freire advocates for, not all people would want to alter the status quo. We saw earlier Wesley White’s (2009) concern that we are asking students to critique the very system they are forced to exist within. And Bandura says about efficacy beliefs that “people achieve the greatest personal efficacy and productivity when their psychological orientation is congruent with the structure of the social system” (2001, p.16). So how do we teach students to be critical of their social system in such a way that they can still have the personal efficacy beliefs that can lead to collective efficacy beliefs necessary for the motivation for social change?

The affective is also underplayed in the literature, although diSessa places the affective as a critical factor in developing p-prims, and the affective is emphasized in Bandura’s framework. Dewey also connects the process of transformation or learning to both metacognition and emotion, and broadens the function of reflection from the backward looking open exploration suggested above by Moon (2008), by explaining: “Emotion is a perturbation from clash or failure of habit, and reflection, roughly speaking, is the painful effort of disturbed habits to readjust themselves” (Dewey, 1922:1983, p.54). Coonan similarly acknowledges the importance of the affective and how it is not as central as it perhaps should be in learning theories:

> “If learning is to encounter and assimilate new information - to ‘stretch’ or ‘broaden’ one’s world view - the process will *necessarily* at some points create such a conflict at the individual

level. Yet little attention is paid in learning establishments to this affective dimension or to the personal anguish that can arise from these challenges to world view and identity" (2011, p.19).

3.7. To teach or not to teach criticality?

So should we be teaching criticality at all, given the lack of consensus on what this means, and given, as Weinberger (2014, pp.80-81), suggests that we are unlikely to ever reach consensus? How do we teach this in a way that isn't still just "initiating students into the dominant logic?" There is a dominant logic of what constitutes criticality, in the same way as there is a dominant logic in science of the hegemony of the abstract and formal. But in this thesis, I will take the position that at the least education should enable the possibility of choice, of agency, and awareness, because, as Giroux suggests, literacy is not simply about the reading and writing ability of subordinate groups but "is also fundamentally related to forms of political and ideological ignorance that function as a refusal to know the limits and political consequences of one's view of the world. Viewed in this way, literacy as a process is as disempowering as it is oppressive" (Giroux, 1987, p.5).

Freire suggests technological developments may be a hindrance to enabling choice (Freire and Macedo, 1987, p.57), when societies driven by mass production lead to exaggerated specialization, as reflected by the drive behind SDR to create a more specialist view of CS. For Freire, critical action is the desired outcome of a critical pedagogy and this comes from critical understanding, as opposed to magic understanding or consciousness, which is characterized by fatalism (1974, pp39-40), or in Bandura's framework, low efficacy beliefs. But we have seen through Bandura's work that these can be context dependent, whereas Freire situates criticality as changing a person's entire outlook. If pedagogy for critical thinking and critical literacy are about becoming 'kinds of people', how can this be reconciled with Bandura and Zuckerman's (2003) theories suggesting that someone can take a critical approach to some aspects of life but not others, and to the literature we have seen above that suggests both literacy and criticality are domain specific?

Weinberger approaches this question from the perspective of knowledge itself, rather than individual students. He re-emphaiszes Bandura and Zuckerman's perspective, that criticality is not assumed to be an ability that once acquired is applicable across contexts or even across time with a context and suggests "For those who have no interest in intellectual rigor, or who lack curiosity (which, by the way, characterizes each of us for at least part of every day), the Net may well be an environment that degrades knowledge. We need to be concerned about all this" (2014, p.105).

If criticality, be it in thought or literacies, is context or discipline dependent, as the literature would seem to suggest it is, then this must be the concern of school teachers as an integral aspect of subject pedagogy. Warschauer says formal education will be responsible one way or another:

> “Electronic literacies can be either empowering or stultifying ... To a large measure, it is in schools and colleges where people will become more or less knowledgeable users of electronic media, critical or less critical readers and writers in an electronic era. The nature of pedagogical practices and school reform will contribute to who becomes the interacting and who becomes the interacted in the network society” (1998, p.21).

3.8. Summary

There may be small windows of opportunity for transformative, pedagogical empowerment through the signifying practices of the curriculum, (Giroux, 1987, p.20) how it is interpreted and played out in individual classrooms. The literature reviewed above is generally more concerned with the boundaries of the constructs under discussion, rather than direct implications for pedagogy. However there are implicit recommendations for learning design.

Freire and Macedo (1987) advocate that schools deal with uncertainty through ensuring creativity is a focus. In order to achieve this “educators should stimulate risk taking, without which there is no creativity” (ibid, p.57), rather than mechanical and rote learning students should be encouraged to doubt:

> “Schools should never impose absolute certainties on students. They should stimulate the certainty of never being too certain, a method vital to critical pedagogy. Educators should also stimulate the possibilities of expression, the possibilities of subjectivity. They should challenge students to discourse about the world. Educators should never deny the importance of technology, but they ought not to reduce learning to a technological comprehension of the world” (1987, pp.57-58).

Freire’s words highlight a central requirement in two ways: the possibilities of expression, expressibility and subjectivity; and not reducing learning to a technological comprehension of the world. diSessa’s, Papert’s and the ScratchEd team’s work increase the possibilities of expression through their alternative, computationally creative ways to express ideas. Although this is not always the case with technology: diSessa explains that even with the addition of tools such as Java, which enabled the creation of dynamic documents, this was still only accessible to experts and therefore “primitive in terms of learnability and expressiveness; it is not intended to be seen or created by ordinary mortals; and it is most certainly not designed to be directly expressive of scientific or any other ideas” (diSessa, 2001, p.218). This led to a medium with two-way potential being used really only one-way, “when considered in relation to the fundamentally new expressive possibilities of computational media – dynamics and interaction” (ibid, p.218).

Freire (1987, p.58) explains that technology “represents human creativity, the expression of the necessity of risk”. But in a technologically advanced society, such advancement has given birth to “the myth of technology and science” and it is difficult for educators to “assume a scientific position that is not scientistic, a technological position that is not technologic” (1987, p.58). We have already seen that Papert struggled against this in education. These societies also promote an “individualistic” frame which he explains “negates subjectivity … denies all dimensions of human agency” as it:

> “… dichotomizes the individual from the social. Generally, this cannot be accomplished, since it is not viable to do so. Nevertheless, the individualistic ideology ends up negating social interests or it subsumes social interests within individualistic interests. The comprehension of the social is always determined by the comprehension of the individual. In this sense, the individualistic position works against the comprehension of the real role of human agency. Human agency makes sense and flourishes only when subjectivity is understood in its dialectical, contradictory, dynamic relationship with objectivity, from which it derives” (1987, p.58-59).

Taking an individualistic approach, Freire claims, is problematic for a critical pedagogy in technological societies, but in addition, a critical pedagogy for Computing is stymied from the start by the contrasting, often competing perspectives of the ‘kinds of people’ involved in the debates. As an educator who crosses the natural/human sciences divide, diSessa explains:

> “On the one side are the scientific, technical folks, and on the other are the literary, humanistic folks. Technical people scarcely ever talk about their own competence as literacy. Mathematical or scientific literacy, if it is mentioned at all, means only knowing enough mathematics or science to be an informed citizen. It is not taken to be a core phenomenon of learning the discipline. The literary, humanistic folks resonate strongly with literacy, but don’t care much about expressiveness in scientific or mathematical domains. Furthermore, they know so much about existing literacy that new literacies are immediately suspect as dilutions, not enhancements” (2001, p.227).

Finally then, to summarise the use of these influential terms of digital literacy and critical thinking in the literature, firstly, critical thinking definitions incorporate notions of reflection, logic, episteme, ways of learning, efficacy beliefs. It is related to becoming a certain ‘kind of person’, but is context and time dependent. It is assumed to be a positive thing, but the notion of proxy efficacy suggests that not all would wish to expend the effort to develop, or carry the burden of, a critical view, and educators should acknowledge affective issues that may arise from a critical education that is essentially encouraging students to question the social systems that they are forced to live within.

All literacies, including digital, can be seen as tools for thought. Pedagogy for a critical literacy is problematic as teachers do not necessarily have the skills to teach it and some literature argues it needs to be explicitly taught, with a different pedagogy to that for discipline content. Existing approaches to literacy particularly ignore the major role of language in the construction of human subjectivity and even those with a focus on meaning-making do so from an individualistic perspective. Computational literacy is seen by some as a mediating tool and computational means can increase the possible forms of expression, but notions of literacy, although fundamentally about expression in any context, are approached differently in natural and social sciences.

Papert laments the disempowering of ideas by school education. Formal education has “a bias against ideas in favor of skills and facts—an idea aversion” and what innovation in education needs is “a new epistemology with a focus on power as a property of ideas and a challenge to the School culture” (2000, p.720). He gives the example of Piaget’s learning by discovery, which in formal education becomes discovery that is “orchestrated to happen on the preset agenda of a curriculum” and hence where the ideas being learned are disempowered. Similarly ideas that knowledge is situated becomes learning in the guise of “real situations”, such as fractions being taught through examples of ‘shopping in a supermarket’, and thus looses the real sense of something personally relevant, instead becoming about “the connection between one set of ideas about which [the student] does not care and another similar set” (ibid, p.723). This is fundamentally an issue of expression and expressibility, which is at the heart of the next three chapters, where the possibilities of expression and subjectivity are shown to be at the core of the research design of this project. To explore these fully, the terms must be operationalized, and the next chapter will discuss this idea of operationalizing through unpicking the terms that have emerged as central to the literature above.

Chapter 4 – Theoretical considerations: from abstraction to levels and expression

And as imagination bodies forth
The forms of things unknown, the poet's pen
Turns them to shapes and gives to airy nothing
A local habitation and a name.

(Shakespeare, A midsummer nights dream)

Introduction

In the previous chapter I have shown the literature indicates that promoting functional and generic aspects of literacy, and divorcing it from specific disciplines, disconnects it from the academic curriculum and makes it more difficult to advocate its importance. Even when framed as domain specific, the multiliteracies perspective appears to focus on how one works across multiple literacies, rather than the nature of or pedagogy for any specific literacy. In developing a curriculum framework for an individual subject, to be commensurate with the structure of existing subjects, it would be very difficult to incorporate the full complexities of 'literacy' as the literature defines it. Similarly in researching the development of what we in essence are looking for when we use the term digital literacy, the operationalization of a construct that ranges in definition from functional reading and writing skills to a complete theory of learning is problematic.

Criticality is also a problematic term that is undermined in the same way as the notion of computational thinking, when the literature focuses strongly on what is meant by critical without having thoroughly defined what is meant by thinking. This construct ranges from a process that removes value to a process that is inherently a construct of value - something evidenced through abstraction in removing complexity and the affective to become 'objective', 'rational' or 'logical', to something that is evidenced by embracing complexity in practice and making informed value judgements within that complexity to enable social change.

diSessa separates these key paths taken by the literacy literature, in a way that can also be applied to critical thinking: by the division into technocentric and ideological views. In technocentric views, the power of literacy comes from transformed thinking: "people become more logical, capable of abstract thought, distanced, dispassionate, critical" (2008, p219). In ideological perspectives, there is a focus on social functions of literacy, literacies, the dependence on social practice, the members and roles in groups producing social strata and the allocation of goods.

In the design of my research project, I advocate a move to a social theory of learning that aims to transcend such divisions of "abstract-concrete; general-particular" (Lave and Wenger, 1991, p.23) with respect to learning. Lave and Wenger explain that learning in their theory is not seen as an "independently reifiable process that just happened to be located somewhere" but rather, learning is “an integral part of generative social practice in the lived-in world” (ibid, p.21). Such a perspective “challenges the very meaning of abstraction and/or generalization [and] has led us to reject conventional readings of the generalizability and/or abstraction of “knowledge.” (ibid, p.23). However the previous chapters have shown the centrality of this notion of abstraction in the literature of Computing education and how it influences the discourse on pedagogy for the subject. Consequently a move to take a social theory perspective on learning in Computing, a perspective that abandons abstract conceptions of knowledge despite abstraction being considered a cornerstone of the content of Computing, needs further justification.

In this chapter then, I will explore the ideas of Sfard, Voloshinov and Wittgenstein among others, to show how the lack of operationalization and the psyche/ideological divide underlying the literature discussed in previous chapters undermines the arguments being put forward, particularly with respect to this central tenet of abstraction. I will begin the exploration by returning to Papert’s themes of epistemological pluralism, and the learning theory that he referred to as constructionism, to argue that even his aims were still impeded by inherent dualisms, which Wenger’s social theory transcends. I will go on to discuss the ethical implications of definitions of abstraction and how even terms such as logic acquire meaning through their use. The implication of this is that I need to be explicit about the uses I am making of such words. I will then discuss the difficulties of operationalising ‘thought’ to justify the move away from divisions of computational and critical thinking or literacies, to a social theory based on competence and knowledgeability in practice to describe learning, and a discursive methodology to explore it.

4.1. Papert’s epistemological pluralism and constructionism

Essentially, with the term ‘epistemological pluralism’, Papert was aiming for students to understand that there are different ways to think about different problems and thus also different ways in to learning concepts and to teach them. But there are more complications associated with the notion of epistemology as highlighted by Hofer and Pintrich (1997), which are paralleled in the literacy and criticality literature, and which may have impacted on the effectiveness of Logo. The definition of epistemology becomes confused not only with ontology as discussed in the previous chapter, but with beliefs about how knowledge is acquired, with learning, instead of beliefs about the nature of knowledge to which the meaning of that term would usually apply. Research around the term epistemology, according to Hofer and Pintrich, suggests it is a function of domain specific knowledge, but there is confusion between domain specific beliefs and domain specific *knowledge* beliefs. Also the research tends to ignore younger children, assuming this is not relevant to them, which reinforces Greene et al’s (2008) view that a sophisticated ontological understanding of a domain is needed before epistemology becomes relevant. Additionally, motivation and context (gender, culture, ethnicity) tend to be ignored and the construct is often framed as individualistic views, rather than socially situated, despite its acknowledged context dependent nature.

Papert and Harel claim that they did not develop a theory of constructionism to suggest it is the 'right' or even 'best' way to view learning, but that it might suit those who favour "forms of knowledge based on working with concrete materials rather than abstract propositions" (Papert and Harel, 1991, p1). Based on Piaget's constructivism, Papert and Harel's constructionism adds that building knowledge structures happens best when learners are creating public entities, be they material or abstract. He suggests the theory particularly "illustrates the sense of the opposition I like to formulate as constructionism vs. instructionism when discussing directions for innovation and enhancement in education" (ibid, p4). But adding this on top of Piaget's existing theory doesn't alter the individualistic situating of learning.

Turkle and Papert themselves critique Piaget in terms of his situating the acquisition of 'formal thinking' as a developmental stage – they say rather it is a style, or a tool, (1990, p.10) which is more in line with Vygotsky (for example 1986) and Wertsch (1991). The premise of constructionism is described thus:

> "Our theoretical conjecture is that degree of closeness to objects has developmental primacy; it comes first. The child forms a proximal or distant relationship to the world of things. The tendency to use the abstract and analytic or concrete and negotiational style of thinking follows" (Turkle and Papert, 1990, p.5).

This reinforces Vygotsky's discussion of 'formal discipline' (1986, pp.146-209). He describes the example of the different level of difficulty between speech and writing as equivalent to that between arithmetic and algebra, and that this is due to the more "abstract quality of written language … The motives for writing are more abstract, more intellectualized, further removed from immediate needs" (ibid, p.181). These two activities then, oral and written speech, are respectively "spontaneous, involuntary and non-conscious, while the other is abstract, voluntary and conscious" (ibid, p.183).

Vygotsky's critique of Piaget (1986, pp.12-57) repositions the use of abstract or formal thinking, giving primacy to social interaction, whereas Piaget gave undirected thought developmental primacy, thus reinforcing the thought/action divide. For Piaget, according to Vygotsky, social speech follows egocentric speech but Vygotsky turns this order around. Vygotsky says the primary function of speech is communication, so earliest speech is essentially a social function, as a child tries to communicate needs. The functions of speech then develop and there is speech for communication and egocentric speech, where the child will think aloud, narrate activities. This speech then develops inner speech. Egocentric speech facilitates the "transition from overt to inner speech" (1986, p.36), thus "the true direction of the development of the direction of thinking is not from the individual to the social, but from the social to the individual" (ibid, p.36).

Piaget situates social factors as an external, alien, coercive milieu, directing and limiting individual expression (ibid, p.44). This creates a dual reality, the child's natural inherent intelligence, and logical forms of thought imposed from outside. This in turn positions socialisation as overriding egocentrism, rather than enabling it. In summary, Vygotsky claims Piaget's theory is missing:

> "… reality and the relations between a child and reality … Piaget's study, which attempts to supersede the laws of causality by the principles of development, loses this very notion of development. Piaget does not put the specificity of a child's thinking in such a relation to logical thinking as to show how the latter is evolving in the child's psyche. On the contrary, Piaget tries to show how logic penetrates the child's thinking, deforms, and finally dislodges it" (ibid, p.52-53).

This necessarily emphasises innate origins of a child's thinking rather than its evolution as a product of development. The dangers of undermining the social development of thought can be seen in Ben-Ari's (1998) application of constructivism to CS education. Using his interpretation of the constructivist theoretical lens, he claims "the concrete way of thinking advocated by Turkle and Papert can only go so far in computer science" and that because he believes this, he argues "their coupling of a learning style with a gender stereotype would lead to the unacceptable conclusion that women are not suited for careers as computer scientists". But this simply indicates a misunderstanding of Turkle and Papert's work, which explicitly proposed 'ways in' to the subject, not an entire pedagogical framework – Turkle and Papert do not suggest that *only* women preferred concrete thinking, or that those 'ways in' were the only way to continue into the depths of the practice. It also infers the hegemony of the abstract and a limited view of what constitutes concrete thinking. This is reinforced by Ben-Ari's comment that, "if software development is ultimately about abstraction, a student incapable of or uncomfortable with abstract thought should be discouraged from studying for the profession of software engineer" (ibid, p.13). This implies a deterministic mindset incompatible with a social constructivist perspective, and a limited view of what constitutes "abstract thought".

4.2. Operationalizing key constructs

With a developmental, socially oriented perspective, we begin to move away from the hegemony of the formal and abstract, where the development of full concepts evolves through both everyday experience and abstract, taught, formalisms (Vygotsky, 1986, pp.146-209). Sfard explains how mathematics is regarded as "perhaps the most striking instantiation of the human capacity for abstraction and complexity" (2008, p.56). Research often focuses on transference or application of formal methods. She gives several examples of how children can solve a computational problem in a natural situation but cannot solve the "same problem" out of context in a different situation. This is fundamentally an issue of abstracting:

> "Solving "the same problem" in different situations means being able to view the two situations as, in a sense, the same, or at least as sufficiently similar to allow for application of the same algorithm. Being able to notice the sameness (or just the similarity) is the gist of abstracting, and the capacity for abstracting is said to be part and parcel of the human ability to "transfer knowledge" – to recycle old problem-solving procedures in new situations" (ibid, p.10).

She further describes how often misconceptions demonstrated by children when learning mathematical concepts are similar to "early historical versions of the concepts" and asks, "Why do today's children think the same way as mathematicians of the past?" (ibid, p.17). Sfard claims that these issues actually stem from a misunderstanding of what we mean by 'misconception', understanding, abstraction and generally about what thinking is and how we operationalize it. The following sections will explore these ideas on objectification in discourse and its effect on use of terms such as abstraction.

Operationalization for Sfard is "conceptual accountability, that is, our being explicit about how we use the keywords and how our uses relate to those of other interlocutors" (ibid, p.42). She notes particular terms including abstraction, misconception and thinking, which are only useful if they have "a definition that specifies what we should look at and what to ignore when trying to decide whether the word is applicable in a given situation" (ibid, p.37), what we should 'abstract' in fact. However, when operationalizing terms, she explains we need to be aware of objectification which can confuse whether a declaration such as "numerical thinking begins with the child's awareness of number conservation" is a definition of or a conclusion about numerical thinking, and which needs an awareness that "defining relates to the ways we talk about the world, not the world as such, and it is up to us, not to nature, to decide how to match our words with phenomena" (ibid, p.x). If we look at how Sfard explains the ways in which objectification of discourse occur, we can see how this is happening in both the literature around computational thinking and the literacy and criticality literature.

4.3. Objectification

Sfard gives the examples of abstraction, concept and learning disability as terms that appear to be "well-delineated" entities, existing in a particular place with a material object-like permanence. This occurs because of the way in which the terms are used in discourse, through a process of reification. As Dewey explains in the reflex arc (see chapter1), where our language can define what at any given moment is acting as stimulus or response, our use of language can also define a construct as at one moment a process or at another as an entity. In learning, objectifications are often associated with claims about abilities and become self-fulfilling prophecies, such as a person being 'bad at maths'. The problem here Sfard explains, is that:

> "As agents of continuity and perpetuation, the reifying and alienating descriptions deprive a person of the sense of agency, restrict her sense of responsibility, and, in effect, exclude and disable just as much as they enable and create … Finally, the self-sustained "essences" implied in reifying terms such as knowledge, beliefs, and attitudes constitute a rather shaky ground for either empirical research or pedagogical practices – a fact of which neither researchers nor teachers seem fully aware" (2008, p.56).

Sfard argues that the notion of objectification explains the earlier problem of why a child can perform a mathematical operation in an authentic situation but not using formal methods – it isn't the same performance, and only our objectification has made us view it as such:

> “…we lose the ability to see as different what children cannot see as the same: We become oblivious to the fact that performing symbolic multiplication such as 4 x 35 and finding the price of four coconuts with the help of banknotes and coins are two very different procedures, which will not be seen as in any way “the same” before the child gains experience with both of them and invests some additional effort in learning to discern their relevant properties. In short, only if we manage to disobjectify our “grown-up” discourse can we become aware that it is the difference rather than sameness that the child notices by default” (ibid, p.58).

This idea of “saming can be seen as the act of calling different things the same name” (ibid, p.169). When we look at this objectifying effect on use of the term thinking, Sfard suggests the discourses “dichotomize the issue and present it in the dual terms of processes such as thinking, cognizing, or learning, on the one hand, and of the products of these processes, such as knowledge, concepts, ideas, on the other hand” (ibid, p.49). Selby and others’ work to define computational thinking, explored in chapter two, explicitly aimed for such a dichotomy, with no recognition of the implications of this. Sfard explains:

> “Being denoted with nouns, the implied products emerge from these stories as phenomena more permanent than the activities that bring them into being and also as fully separable from these activities, in that each one of them is now believed to be “constructible” or “acquirable” in many different ways” (ibid, p.49).

Sfard also suggests that the remedy is simply “to acknowledge the fact that while speaking about objects such as knowledge or concepts, we speak in fact about our own discursive actions, whose rules are quite different from those that govern material objects” (ibid, p.58).

Understanding and meaning are often used as equivalent and both are usually objectified. Meaning is seen to be something that can be expressed and thus transferred between people, and understanding is thus seen as a state of ‘holding’ the right meaning, and therefore is a diagnosable state. Yet Sfard highlights the research on ‘misconceptions’ that shows children may show signs of good understanding in one situation yet show “incomprehension and helplessness while dealing with seemingly the same concept or procedure in another situation” (ibid, p.60). Objectification, as for epistemic or ontological views, works differently in different domains. The attribution of permanence and repetitiveness may be helpful and appropriate for mathematics, physics or chemistry, but “may be rather ungrounded in research on humans and their activities” (ibid, p.56). Further, whereas objectification can be helpful in natural sciences, it is “likely to become unhelpful, or even harmful, when applied to people and their actions” (ibid, p.56). Abstraction, a central mechanism for natural sciences, can be harmful as a thinking tool in social sciences, and so for the pedagogy of natural sciences, as I will explore in section 4.7. But first, I need to operationalize thinking, in line with Sfard’s recommendations.

4.4. A social perspective on 'thinking'

Sfard's emphasis on operationalization of key terms is particularly pertinent for 'thinking', where the meaning of the word is taken for granted and so questions such as:

> "… Is there thinking without speech? appears to be about facts and, as such, is interpreted as requiring an empirical answer. At the same time, the absence of an operational definition precludes the possibility of a sound empirical study. This logical entanglement is a reliable prescription for insoluble disagreements" (ibid, p.95).

In the literacy literature explored in the previous chapter, we saw Kalantzis et al (2016) define thinking as the combination of representation and communication, in an attempt to focus on the language based nature of thought. Sfard summarises Vygotsky's view, which is similarly language focused:

> "According to him, studying thinking by attending to words and thoughts as if they were separate entities would be like trying to find out the properties of water by looking at those of hydrogen and oxygen … He viewed thinking and speaking as having separate "genetic roots" and as remaining separate until the child learns a language. Later, when both interpersonal and intrapersonal communication begin to occur mainly in language, there is no point in talking about separate processes of "producing" and "expressing", thought" (Sfard, 2008, p.97).

Sfard employs the term *commognition* to attempt to transcend this unhelpful divide between speech and thought, or communication and representation, and to situate them as "two facets of the same phenomenon" (ibid, p.x). She suggests that thinking can "be thought of as the type of human doing that emerges when individuals become capable of communicating with themselves the way they communicate with others" (ibid, p.91). But commognition perhaps still implies something an individual does.

Voloshinov, who built on Vygotsky's work, goes further and suggests the divide to be transcended is even deeper, in that notions of social and individual are "fundamentally false". He explains that natural and socioideological concepts of 'individual' are often confused. The content of the individual psyche is social, and ideological phenomena are just as individual as pyschological phenomena. So: *"… there is no basic division between the psyche and ideology; the difference is one of degree only"* (1973, p.33).

Voloshinov begins his argument against the individual/social division with a critique of functional psychology, which he claims places ideological phenomenon such as logical concepts or ethical values into a "transcendental realm" (ibid, p.31) and sets it in opposition to individual consciousness. But thought begins, comes into existence, "with an orientation toward an ideological system of knowledge where that thought will find its place". Thus:

> “My thought, in this sense, from the very start belongs to an ideological system and is governed by its set of laws. But, at the same time, it belongs to another system that is just as much a unity and just as much in possession of its own set of laws – the system of my psyche. The unity of this second system is determined not only by the unity of my biological organism but also by the whole aggregate of conditions of life and society in which that organism has been set” (ibid, p.35).

Applying this approach to research, Sfard agrees that it is impossible to understand acts of communication that are uniquely human “without considering the collective activity of which they are a part. That is, some recurrent individual ways of acting acquire their meaningfulness and effectiveness via patterns visible only at the collective level” (Sfard, 2008, p.85). The methodology of this research project, as I will explain in chapter 6, aims to explore patterns at both individual and collective levels. Given this informs the methodological design, what is meant by ‘levels’ will also be explored below.

4.5. Abstraction and level confusion

Meaningfulness becomes central for Sfard and Voloshinov, in avoiding individual notions of thought and speech and focusing instead on sign. Sfard describes the recursive nature of language that differentiates human communication and allows increasingly abstract levels of thought. She explains that:

> “Because reasoning can be described as the art of systematic derivation of utterances from other utterances, its metadiscursive nature is implied in its very definition. In other words, recursion underlies reasoning processes because reasoning, as an activity of exploring relations between sentences, requires going beyond the sentences themselves, to metadiscourse … In the absence of recursive communication we would be able to talk only about things that we can actually point to – and would thus remain “captives of our visual field”” (ibid, p.110).

These metalevels of language contribute to objectification and confusion over the relation to reality, after all, “Our language does not merely describe what there is – it is responsible for what we consider as real” (ibid, p.72). There is a lack of awareness, or at least recognition, of these levels as Sfard explains, “The fact that the majority of our commognitive acts are metastatements of a certain order has been overlooked even by those philosophers and cognitive scientists who, in the attempt to fathom the secret of human thinking, turned to what they called metacognition or thinking-about-thinking, ideas clearly related to the phenomenon of recursivity” (ibid, p.108).

The relation to reality in levels of language is commonly how the term abstracting is used, such as the creation of “concepts that do not refer to tangible, concrete objects”. Sfard defines ‘concept’ as:

> “… a symbol together with its uses. (Here, I am using the word symbol as more encompassing than word.) … This is the case, for example, when an interlocutor uses the word cat for any member of a certain family of four-legged long-tailed creatures, as opposed to using specific symbols for each catlike animal that strays into her field of vision. To arrive at such symbolic

"saming" of the given set of individuals one needs to perceive them as in some ways similar … the main element of this process is learning how to disregard differences" (ibid, p.111).

She goes on to explain how abstracting in this way works similarly for mathematical operation such as "using the single word multiplication for discursive processes as different as repeated addition and finding a part of a quantity" (ibid, p.111), where, in order to see the similarity, one needs to reflect on past discursive events. From this, Sfard thus defines abstraction as the discursive activity of concept creation and notes that, "The fact that abstracting can only occur within a recursive symbolic system is thus implied by the very definition of this discursive activity" (ibid, p.111). The objectification of concepts and creation of new levels is how the field of mathematics develops, or in Wittgenstein's (Diamond, 1975) and diSessa's (2008) terms, how maths is 'invented', as Sfard explains:

> "New mathematical objects produced in such a transition are the result of saming and encapsulating of lower-level objects and of reifying lower-level processes. The compression of the discourse resulting from objectification triggers a new expansion that will be eventually followed by new attempts at compression. This is, basically, how mathematical discourses evolve throughout history" (Sfard, 2008, p.262).

CS has much in common with mathematics, as Furber (2012, p.4) points out that it, "provides a 'way of thinking' in the same way as mathematics does", (ibid, p.3) and we can see here that mathematics is an evolving discourse.

Sfard adjusts the focus from concepts, and the differentiated notions of spontaneous/everyday and scientific/formal concepts, into terminology of discourses. She defines discourses as "The different types of communication, and thus of commognition, that draw some individuals together while excluding some others" (Sfard, 2008, p.91), and suggests that these can be "literate" or "colloquial". Colloquial discourses, in which "the metaphor of object is omnipresent" (ibid, p.68), "are often mediated by images of concrete objects, which are referred to with nouns or pronouns and which are effective in this communication-coordinating role whether they are actually seen or just imagined" (ibid, p.148). Literate discourses such as those "practiced by professional communities of researchers are usually several metadiscursive layers above those one encounters in schools" (ibid, p.134) and are "visually mediated mainly by *symbolic artifacts*" (ibid, p.148).

She describes the job of a teacher in a classroom as "trying to narrow the gap between the two extremes, and … to replace some of the colloquial substantiation routines with literate ones, thus introducing a strong element of purely discursive manipulation" (ibid, p.232). This process happens as children try to transfer their narratives from colloquial to literate – for example, they need to move from answers such as "Because it looks like a triangle" to "Because it has three sides": moving from the "merely necessary entailment of being a triangle to the necessary-and-sufficient condition for the triangularity" (ibid, p.232).

But even with Sfard's very explicit operationalization of her constructs, there is still an objectifying process in categorising discourses with labels such as 'colloquial' and 'literate'. With Vygotsky's categorisation of concepts, there is an inference of spontaneous being at one end of a scale and scientific at the other, so it continues to facilitate exalting the scientific and allowing an inferred hierarchy. Sfard has highlighted the importance of levels in discourse and perhaps refocusing on levels can provide an alternative that incorporates the recursivity of language in its correspondence to reality. Resnick, Papert's pupil and the lead of the ScratchEd team, gives a really interesting take on this, which informs the methodological design of this study.

In categorising discourse, and 'types' of concept, we are not yet avoiding the continuation of an academic/vocational, theory/practice divide. I have shown Voloshinov extends these divisions to an individual-social divide that he attempts to overcome through focus on the sign. But here even the notion of meaning becomes problematic, as we will see later. All these divisions are attempts to manage complexity, or as Dewey says, part of our quest for certainty. This isn't driven by the uncertainty of experience - that is not what we object to - but rather the potential for peril within that uncertainty. If we were confident that any of the possible uncertain outcomes would be positive, we would not struggle as we do with uncertainty. Hence the importance of the affective in how we deal with the complexity of our world and the associated uncertainty (Dewey, 1929:1984).

Colloquial and literate discourses, as Sfard has described them, are in fact just different levels of discourse, rather than essentially different 'types', and if we can avoid seeing them as essentially different, we do not need to elevate the status of one over the other. Sfard has shown us the recursive levels within discourse and explains that we move *between* these levels: "creation of subsuming discourse, its objectification, and its deritualization are not straightforward processes. These processes involve frequent alternating between object-level and meta-level discourses, and they require time and effort" (2008, p.266).

Wilensky and Resnick (1999) suggest a way of describing the world that works on levels of complexity. They relate this most particularly to science, but there are clear parallels with the recursive levels Sfard explores in all discourse. Resnick is concerned with level confusion, which we can see is exacerbated, if not entirely caused, by objectification. Wilensky and Resnick position the notion of levels as a complexity construct but say it hasn't been a central focus for research in that area at the time of their writing. Their aim is: "By foregrounding the notion of levels, we hope to enable people to transform their view of systems, using levels as a framework for seeing systems from multiple perspectives" (1999, p.6). This is clearly still driven by the motivation behind Papert's project, for supporting new ways of thinking.

To explain the notion of levels, Wilensky and Resnick use the examples of traffic jams and waves. Crucially, levels do not imply hierarchies. They can be viewed as nested systems, parts of wholes, or emergent levels that arise through interactions at lower levels. e.g. a traffic jam emerges from cars. But they are fundamentally "levels of description that can be used to characterize a system with lots of interacting parts" (ibid, p.3). The whole/part relationship can complicate the notion: in general use, a month can be seen as part of a year, but a year could be viewed as a long month: they are both employed as purely temporal measures, and as such, one is a divisible unit of the other. However, although individual cars are part of a traffic jam, a traffic jam can in no way be viewed as one long car. A traffic jam is not just an accumulation of cars, but is the way in which they interact, the way they enter into and leave the traffic jam. Cars are a specific singularity, whereas a traffic jam is a behavioural phenomenon.

A traffic jam works in a similar way to a wave where, “In an ocean wave, it is the energy that moves, not the water molecules. Similarly, with a wave travelling along a rope: pieces of the rope move up and down, but the wave moves along the length of the rope” (ibid, p.4). Wilensky and Resnick recognise the role of language in this perception, in the way “Languages make a fundamental distinction between the singular and the plural” (ibid, p.6). They go on to explain:

> “Our language, typified by the use of the singular pronoun “I,” reflects (and, perhaps, reinforces) this view. But the new distributed models of mind require a new stance in thinking about the “self” as sometimes an “I” and sometimes a “we.” …. Objects that are viewed as singular at one level are best viewed as plural at another level. The ability to shift levels, viewing the same object as either singular or plural, depending on the situation, is a prerequisite for building deep, scientific understandings of phenomena…. singular or plural depends on what question you are trying to answer—and which stance (that is, which level of description) provides a better explanatory account of the question” (ibid, p.7).

They argue that level confusion “and “slippage” between levels” (ibid, p.1) leads to “misunderstandings about patterns and phenomena in the world” (ibid, p.2), and claim that a focus on levels would encourage interdisciplinarity and would act to unify “different domains of knowledge in the humanities and social sciences as well as the natural sciences” (ibid, p.4). They discuss a deterministic mindset, and suggest this occurs when people “see patterns in the world, [and] they tend to assume centralized control, even if it doesn’t exist. And when people try to create structures in the world (such as organizations or technological artifacts), they often impose centralized control even if it is not needed” (ibid, p.7).

4.6. Abstraction, logic and ethics for criticality

Barba (2016) discusses the increasing focus on computational thinking and particularly abstraction in the Computing world. She essentially highlights the positive aspects of objectification for the practice of Computing in differentiating between abstraction and objectification:

> “Abstraction is not the badge of computer science: it’s integral to mathematics, philosophy, and all of science! And why fixate on decomposition, patterns and algorithms, and say nothing about variables and debugging? Naming things is essential to computing, and the idea of objects endowed with certain inherent properties is computationally powerful. There are many ways to draw on computing as a representation of knowledge, to help us think. The operational aspect of making problems computable is essential, but not aspirational. Most people don’t

> want to be a computer scientist, but everyone can use computers as an extension of our minds, to experience the world and create things that matter to us" (Barba, 2016).

Computing here is shown to actively encourage, or depend upon objectification. Yet, she relates back to Papert's "powerful ideas" and suggests, as he did, that a focus on the abstract is disempowering, as ideas such as probability become disempowered in schools when "reduced to shallow manipulation that seldom connects to anything the student experiences as important" (Papert, 1996, p.100).

But this is abstraction from a natural science perspective, which the literature has shown is helpful. To explore the construct of abstraction from a social sciences perspective, Pin-Fat (2008) turns to Wittgenstein and his focus on 'language-in-use'. Her starting point, the purpose of the exploration, is to be aware that "how we think about the world affects how we live in it. It is of course not just a matter of how we live in it on our own, but how we live in it with others" (ibid, p.23). Pin-Fat describes a hypothetical situation called the ticking time bomb scenario, used to test the absolute prohibition against torture, to ascertain whether there may be circumstances in which it is justified. The scenario abstracts the core issue by eliminating specific aspects of the situation. In order to achieve this "one must believe that theory (thinking about the world) and practice (doing things in the world) can be separated. A separation is made and assumed to be possible" (ibid, p.29). The abstraction is designed to reduce the problem of torture to two competing values, and thus implies that the simplification aids decision-making. The abstraction is also constructed from an 'external' perspective, rather than being representative of all perspectives in the scenario. Pin-Fat explains how the clear boundaries around the scenario thus begin to break down and likewise therefore the strict separation of theory and practice.

Like Sfard, Pin-Fat highlights Wittgenstein's focus on language games, which create our reality. She explains:

> "This does not mean that there is no external reality. But it does mean that we are wholly dependent upon language to make sense of and understand the world we live in … how we think about the world is regulated by our language games or practices. In turn, if our thoughts are regulated by language, it means that our thoughts are practices: ways of being in the world" (ibid, p.37-38).

This perspective leads to a particular path for research, both questions and methods, according to Pin-Fat. The ticking time bomb scenario situates reason as abstraction: an issue is identified, a hypothetical scenario provided, and from that global principles of justice are deduced. She explains that a different engagement with this picture is to trace its effects rather than engage with its 'truth' or 'falsity'. The latter separates theory and practice, and then immediately faces the problem of how to reunite them. Abstraction is "deliberately designed to strip away all this information and ask us to make decisions in the absence of the much messier, complicated fabric of global politics". Pin-Fat describes how a report commissioned by Donald Rumsfeld used the ticking time bomb scenario to justify the U.S. use of torture in exceptional circumstances, flagrantly contradicting the absolute prohibition. Thus “we must ask whether the ticking time bomb scenario is complicit in the use of torture because the use or practice of its picture of reason makes torture possible” (ibid, p.41).

To come back to our question of whether criticality should be an inherent part of a curriculum subject, particularly Computing, Pin-Fat gives a good justification here, particularly in the curriculum context of promoting computational and other ‘ways of thinking’, and suggests that, despite Bandura’s description of the burden of personal agency: “if we ignore the impact our ways of thinking have on the world, we can find ourselves complicit in what happens in ways we might not wish to be” (ibid, p.24).

Use then becomes a crucial factor in the ethics of abstraction. Wittgenstein gave a set of lectures in 1939 to a group at the University of Cambridge, among whom Alan Turing was a participant, where he attempted to unpack the foundational nature of mathematics. He explains the difference between a mathematical and an experiential proposition in exploring the question: why do we count? He uses the specific example of why do we weigh: “to see what the weight is? To see if we can lift it? To see how we might balance it? The difference doesn’t lie in what is written down but in the use made of it” (Diamond,1975, p.114 – 115).

Over the course of the lectures he argues that even the definition of logic, a form of thought privileged in the Computing community, depends upon its use, and is given its meaning through use. Wittgenstein explains how mathematical terms and their transformations, which have no material reference at their pure level, become laws of logic, abstraction and maths. He argues that “Logic is not determined by a consensus of opinion but by a consensus of action” (ibid, p.183) and similarly:

> “Mathematical truth isn’t established by their [mathematicians] all agreeing that its true – as if they were witnesses of it. *Because* they all agree in what they do, we lay it down as a rule, and put it in the archives. Not until we do that have we got to mathematics” (ibid, p.107).

Wittgenstein discusses the problem with use of the word meaning in exploring logic. We use “meaning” in different ways: as the “criterion for meaning, something which passes in our minds when we say it, or something we point to, to explain it”; but also as “the use we make of the word or sentence as time goes on … The connexion between these two criteria is that the picture in our minds is connected, in an overwhelming number of cases- for the overwhelming majority of human beings - with a particular use” (ibid, p.182). Wittgenstein uses a random word assignation to more fully explain this, with the example of pointing, which is understood in a certain way and which leads to the point that:

> *“… we all make the SAME use of it.* To know its meaning is to use it *in the same way* as other people do. “In the right way” means nothing” (ibid, p.183).

We have seen that rationality and logic underpin some definitions of criticality as well as computational thinking, and we have seen Papert’s concerns that logic takes a hegemonic position in discourse about computational thought, but even in these domains, from Wittgenstein’s perspective, the idea of ‘one right way’ is meaningless – logic is only a ‘law of thought’ according to its meaning in use, not as a transcendental essence.

4.7. Thinking, meaning, expression

If terms such as logic are to underpin definitions of critical thinking or computational thinking, then we must be clear about what use is being made of these terms. Sfard explains that it is possible to disobjectify discourse on terms such as thinking through operationalizing “without reference to “private” entities”. Drawing on Wittgenstein she explains how this is possible:

> “If we are able to communicate about thinking (or pain, or any other process traditionally considered as inherently private) in our daily lives, there must be public criteria for identifying this phenomenon in its multiple manifestations. If so, there is no reason why we should not be able to use these very same public criteria, alas in a more explicit and systematic way, while trying to tell new, more insightful stories about thinking. All one has to do to operationalize a discourse is to observe how people use words and to tease out rules according to which they do so. When Wittgenstein defined meaning as “the use of the word in language,” he both instantiated and described this simple idea of operationalization” (Sfard, 2008, p.75).

From Dewey’s perspective, the term ‘thought’ is a variety of processes, of use, through which meaning is created: “In any event, it is desirable that the teacher should rid himself of the notion that "thinking" is a single, unalterable faculty; that he should recognize that it is a term denoting the various ways in which things acquire significance” (Dewey, 1910:1978, p.211). Voloshinov (1973) too argues that there is no experience without meaning, and that meaning comes through language, through sign. Without sign, ‘experience’ is just reaction, a physiological phenomenon, but when given meaning through sign, it becomes human experience: “What makes a word a word is its meaning. What makes an experience an experience is also its meaning” (ibid, p.26). He explains how the complexity of language levels emerge as concepts and meanings develop based on one’s existing understandings: “A sign can be illuminated only with the help of another sign” (ibid, p.36).

Consequently, if understanding is “an act of reference between the sign apprehended and other, already known, signs” and “Multiplicity of meanings is the constitutive feature of word” (ibid, p101), then interpretation of signs is always unique to an individual because their perspective of already known signs, those experienced, and the organisation and interpretation of them, must be unique, because the location each individual embodies is unique (Holquist, 1990, p.12, p.30). But this does not undermine the social nature of these understandings, which are always situated:

> “The understanding of any sign, whether inner or outer, occurs inextricably tied in with the *situation in which the sign is implemented*. This situation, even in the case of introspection, exists as an aggregate of facts from external experience, the latter commenting upon and illuminating a particular inner sign. It is always a *social situation*. … Thus any deepening of

> introspection can come about only in unremitting conjunction with a deepened understanding of the social orientation [in which the experience occurs]" (Voloshinov, 1973, p.37).

And so meaning does not belong to a word or the speaker or listener, but is "the *effect of interaction between speaker and listener produced via the material of a particular sound complex*" (ibid, p.102).

As I showed earlier that Vygotsky claimed the function that motivates the social development of speech is to communicate, the notion of expression is thus central to thought for Voloshinov: "There is no such thing as thinking outside orientation toward possible expression and, hence, outside the social orientation of that expression and of the thinking involved" (ibid, p.90). It is similarly central to experience:

> "… any experience is expressible, i.e. is potential expression. Any thought, any emotion, any willed activity is expressible. This factor of expressivity cannot be argued away from experience without forfeiting the very nature of experience" (ibid, p.28).

As there is no experience without meaning, embodiment in signs, it is also expression that "first gives experience its form and specificity of direction" (ibid, p.85). Voloshinov argues then that "*Outside objectification, outside embodiment in some particular material* (the material of gesture, inner word, outcry) *consciousness is a fiction.* It is an improper ideological construct created by way of abstraction from the concrete facts of social expression" (ibid, p.90). Consciousness is an objective fact as part of existence, a force which, while an internal "embryo of expression" (ibid, p.90) is too small a piece of existence to have impact, but once it enters into "the power system of science, art, ethics, or law, it becomes a real force, capable even of exerting in turn an influence on the economic bases of social life" (ibid, p.90). This consciousness enters in organised ideological "modes of expression (science, art, and so on)" but even in a vague form of incepted thought it is a social event, not an inner act. He goes on to explain: "The expression of an experience may be realized or it may be held back, inhibited. In the latter case the experience is inhibited expression … Realized expression, in its turn, exerts a powerful, reverse influence on experience: it begins to tie inner life together, giving it more definite and lasting expression" (ibid, p.90).

In the previous chapter, it was the idea of expression that diSessa showed was perhaps underplayed in the literature particularly when applied to scientific ideas. He saw computational literacy as an entirely new literacy, because it enabled an alternative expression of complex, abstract ideas, and he gives examples of how a computer program can be more expressive of underlying ideas than an algebraic expression for science (diSessa, 2008, p.223). He suggests that particular representations have different levels of expressiveness for particular ideas, and is concerned that the "props of literacy" have been backgrounded in socially oriented literacy studies, which is concerning in terms of preparing students for a world where they will need, "a far larger component of meta-representational competence than is necessary now" (ibid, p.228).

Expressiveness then is an important consideration for Computing pedagogy, but is not foregrounded in any of the computational or critical literacy literature explored so far. From diSessa's research with computational tools, he acknowledges that to answer important questions around scientific abilities and literacy, new frameworks are needed:

> "How do intellectual powers, such as competence in mathematics and science, interact with social functions of literacy, especially destructive ones, such as social class divisions and preservation of privilege and power? No one has good answers to those important questions. In coming to address them, we will need better and more refined theories of literacy that take into account (a) the nature of humans as knowers, learners and actors, (b) the extensions in thinking and doing made possible by particular new media and (c) the social embedding of new literacies, including the dynamics that might bring them into existence." (ibid, p.243).

In contrast to constructionism, from the literature in this chapter we can see that the nature of humans as knowers, learners and actors begins with social interaction, rather than individual acts, albeit with social artefacts. Thinking (as the term is usually employed, in relation to human consciousness given meaning, rather than lower level cognitive functions such as perception or physiological response), is also essentially an act of language, and further, from Pin-Fat (2009, p.38) "thoughts are practices: ways of being in the world".

So what is needed for exploration of learning with the RPi is a theoretical framework that encapsulates a non-dualistic, levelled rather than categorised entity approach, enabling a developmental, temporal, perspective without assuming a hierarchy that perpetuates the hegemony of the abstract; a framework that situates thought as the social act it is, and allows us to discuss pedagogy for ways of thinking with terms that we can operationalize while avoiding unhelpful objectification. Following Papert's work, Wilensky and Resnick have argued for, not only developing awareness of levels as a pluralistic approach in the content of teaching, but also in the methods for pedagogy.

The digital literacy and critical thinking literature in its increasing complexity was suggesting in various ways that their frameworks provided theories of learning. From the playing out of the curriculum battle in Computing, to the complex and diverse definitions of digital literacy explored in chapter three which is problematic for a curriculum to encapsulate, I would argue that a theoretical framework for learning Computing needs, perhaps more than any other subject, to avoid a knowledge/practice divide. Computational thinking and abstraction are pushed as the key aspects of the subject, but this chapter has shown that these are not the individualistic, exalted entities which the academic Computing community situate them to be, nor is the notion of criticality. It is in *use*, in modelling and problem solving, as a bridge between what Papert referred to as 'abstract' and the 'concrete', acknowledging now the limits of this duality in itself, that the power of the subject lies.

4.8. A theory of learning for processes of perspective and participation

In Sfard's view, learning happens through social interaction and thus metalevel learning comes through differences in ways of communicating rather than discord between endorsed narratives, or frames of reference and external evidence.

> “Rather than assuming that what we say (think) about the world is determined by what we find in the world, it claims a reflexive relation between what we are able to say and what we are able to perceive and endorse. Most of the time, our discourses remain fully consistent with our experience of reality. We need a discursive change to become aware of new possibilities and arrive at a new vision. We thus often need a change in how we talk before we can experience a change in what we see” (Sfard, 2008, p.258)

This is the case for learning and for frameworks we use to explore learning. Sfard outlines a number of frameworks based on a participationist view, including those based on activity and practice. Whichever term is central, she claims “the strength of this unit is in the fact that it has both collective and individual “editions”” (ibid, p.80).

The notion of identity is also central to a number of participationist frameworks and Sfard suggests that although the term identity “has been criticized for its being pervasively unclear and undefined… it can be operationalized through the notion of subjectifying” (ibid, p.290). Self-subjectification “occurs when the subject of a reifying utterance is also its author” (ibid, p.113) and leads to statements that relate to efficacy beliefs such as “I am bad at maths”. This will inform an important aspect of the design of the method for this research project as described in chapter 6. But first, in the following chapter I will describe Wenger’s participationist social theory of learning, which I will argue addresses the requirements argued for in this chapter and leads to a compatible methodological approach that accounts for collective and individual levels.

Chapter 5 - A social theory of learning for learning with RPi

“That element of tragedy which lies in the very fact of frequency, has not yet wrought itself into the coarse emotion of mankind; and perhaps our frames could hardly bear much of it. If we had a keen vision and feeling of all ordinary human life, it would be like hearing the grass grow and the squirrel's heart beat, and we should die of that roar which lies on the other side of silence. As it is, the quickest of us walk about well wadded with stupidity.” *(Eliot, Middlemarch)*

Introduction

The previous three chapters have explored the constructs of computational and critical thinking and digital literacy in terms of the assumptions underlying the way this language is used in the literature. I have argued that ‘thought’, at the level to which notions such as critical and computational apply, is first and foremost a social phenomenon, so in exploring it we need a framework that takes a social perspective and guides the research questions and methods accordingly. The theories of Wenger may constitute such a framework.

Wenger’s 2001 Communities of Practice is a participationist approach that I said in the introduction to the previous chapter rejects “conventional readings of the generalizability and/or abstraction of “knowledge”” (Lave and Wenger, 1991, p.23). In this theory abstract and concrete are not “two poles of interest” but rather “points of departure to explore and produce an understanding of multiply determined, diversely unified – that is, complexly concrete – historical processes, of which particularities (including initial theories) are the result” (Lave and Wenger, 1991, p.23). Lave and Wenger emphasise *use* in considerations of abstract-concrete, general-particular. They explain:

> “Generality is often associated with abstract representations, with decontextualization. But abstract representations are meaningless unless they can be made specific to the situation at hand. Moreover, the formation or acquisition of an abstract principle is itself a specific event in specific circumstances” (Lave and Wenger, 1991, p.21).

I propose this theory provides the best explanatory account of learning to explore activities with RPis in my research project, and this chapter will describe the key constructs of the theory in order to demonstrate how this is the case.

5.1. A social theory of learning

The core text of Wenger’s theory is *Communities of Practice: learning, meaning and identity* (1998). Wenger originally worked in the area of artificial intelligence and claims that the inquiry that led to the theory was based on this work, and finding that “the philosophical questions we ask of it [artificial intelligence] – questions about intelligence, knowledge, and learning – are often not well-defined to start with because we do not place them in the context of human practices” (1998, p.292). The concept of a community of practice (henceforth CoP) is part of a broader framework for social learning based on the notion of identity in practice. Wenger (2010) describes how the CoP concept has been widely used across many disciplines and is now often used by practitioners as a goal or technique, as people try to manufacture what they call communities of practice without due regard to the concept's original formulation.

Social theory aims to organise a perspective on the world rather than generate statements that can be true or false (Wenger-Trayner, 2013, p.105) and Wenger's theory uses terms that become technical terms and do the work of providing new ways of making sense of the world (2013, p.105). Wenger describes the painstaking work of developing terms for inclusion in theory, and says "The value of a theory as a perspective is rooted in a systematic discipline of language" (ibid, p.108).

The key components of Wenger's theory are meaning, practice, community and identity, elements that are "interconnected and mutually defining" (1998, p.5). Knowledge in this theory "is a matter of competence with respect to valued enterprises" (ibid, p.4) and knowing is "a matter of participating in the pursuit of such enterprises" (ibid, p.4). Producing meaning is the outcome of learning, and is "our ability to experience the world and our engagement with it as meaningful" (ibid, p.4).

Learning is not something we decide to do but something we constantly do and can't switch off. We learn as instinctively as we breathe, and the process of learning to be a gang member is the same as learning how to be a pupil in a school. However organised schooling, as "an educational form is predicated on claims that knowledge can be decontextualized, and yet schools themselves as social institutions and as places of learning constitute very specific contexts" (Lave and Wenger, 1991, p.24). Formal education then is just one specific type of learning situation, centred on learning more formal content as defined by curriculum, but much more learning goes on in these settings than that planned for by teachers.

Design in Wenger's terms is "a systematic, planned and reflexive colonization of time and space in the service of an undertaking. This perspective includes not only the production of artifacts, but also the design of social processes such as organizations or instruction" (1998, p.228). Learning in fact can't be designed for, instead learning is always a response to a design: a teacher will set 'learning objectives' for a lesson, a lesson which is situated in a particular classroom space, and the pupils will be learning something during the lesson, but not necessarily what the teacher has planned. For instance, while the planned objective is 'to understand *while* loops', some pupils may instead or simultaneously be learning that programming entails multiple failures, the rules of an online game that they have been told not to play in class, or how to manage conflict in friendship groups.

For Wenger, learning is caught in the middle of social structure and situated experience, between social practice and identity: "it is the vehicle for the evolution of practices and the inclusion of newcomers while also (and through the same process) the vehicle for the development and transformation of identities" (ibid, p.12-13). In this way it works across the levels (not entities) of individual and social experience, rejecting "a dichotomy between individual and social … At a collective level it theorises a local definition of competence negotiated by the community through participation … At a personal level, the theory embodies agency in processes of identification" (2013, p.110).

From the earlier 1991 text to more recent developments in the theory (see for example 2013, 2015) the key emphasis of social practice underlying the CoP theory is:

> "… the relational interdependency of agent and world, activity, meaning, cognition, learning, and knowing. It emphasizes the inherently socially negotiated character of meaning and the interested, concerned character of the thought and action of persons-in- activity. This view also claims that learning, thinking, and knowing are relations among people in activity in, with, and arising from the socially and culturally structured world. This world is socially constituted; objective forms and systems of activity, on the one hand, and agents' subjective and intersubjective understandings of them, on the other, mutually constitute both the world and its experienced forms" (Lave and Wenger, 1991, p.28).

More detail on the key constructs of Wenger's original CoP theory are explained in Appendix A, but as I am applying the theory to explore school level education, it is important to introduce the notion of boundary and landscapes of practice here.

5.2. Boundary, locality and the landscape of practice

CoPs do not exist in isolation but in relation to others across a social landscape of practices. Boundaries can have reified markers of membership but these aren't inevitable where barriers to participation exist – Wenger gives the example of a clique in a school playground where the boundary can be a cruel reality without reification (1998, p.104). Boundaries do not necessarily map to institutional boundaries, as CoPs define themselves around engagement in practice, which as we have seen does not necessarily imply a formal status. CoPs can organise themselves around boundary objects: artefacts, information or even natural features, objects that belong to multiple practices act as a "nexus of perspectives", and thus have potential to be a boundary object where perspectives need to be coordinated (ibid, p.107-108). The RPi can be seen as such an object between and within communities of electronics hobbyists, academic computer scientists and educationalists, but it is important to see here that this theory does not try to suggest a boundary object would be a coordination of abstract and concrete knowledge, but a nexus around which perspectives in practice, which include both 'abstraction' and 'concreteness' points of departure, emerge and develop.

Another way in which CoPs connect is brokering, where members of a CoP bring in their alternative experience and perspectives from other practices, drawing on their multi-membership. This often happens more with those on the periphery of a group rather than full or central members. Participation and reification create connections across boundaries. The former comes through, for example, vicarious experience through people we are close to, though this means, "our knowledge of these practices inherits the partiality of those who give us peripheral access to them" (ibid, p.111).

Reification connections across practices “transcend the spaciotemporal limitations inherent in participation” (ibid, p.110). New practices can emerge from boundary practices, seen for example in the new UK NHS career paths of clinical bioinformaticians, which have emerged from practices around medicine, health informatics and CS, as means of capturing and analysing medical data have exploded the possibilities for areas such as genomic data research.

Boundaries are places of discontinuity, peripheries to continuities, overlaps and connections, hence the importance of the term in education. Peripherality “can be a position where access to a practice is possible, but it can also be a position where outsiders are kept from moving further inward” (ibid, p.120). This can be a daunting or welcoming position and here expressibility is important. In the CoP theory, this latter construct has been foregrounded more in recent developments, which I will come to in the following section.

Constellations of interconnected practices “define relations of locality” (ibid, p.130), providing a perspective on notions of local and global. Technology provides new forms of participation in the global but “we do not engage with it” (ibid, p.131). We can go as far as watching Raspberry Jams in Singapore on Skype, but we don’t engage with the practice locally. The local and global also relates to the issue of abstraction as discussed in the first part of this chapter: as technology advances ways to explore patterns on a large scale, the trade off is that we can lose “participation in the complexity of situations and their local meanings … They can see more only by seeing less. What they end up knowing is something different, which has relevance in its own context, but which does not subsume the perspectives it attempts to incorporate” (ibid, p.131-132).

A CoP acts “*as a locally negotiated regime of competence*” (ibid, p.137). Competence then is defined as what can be “recognised as competent participation in the practice” and this is defined by the practice itself, rather than some form of reified criteria. In order to learn in practice, “an experience of meaning must be in interaction with a regime of competence” (ibid, p.138). This regime of competence in turn becomes a regime of accountability, the history of the practice and what matters to the community. Newcomers to a Raspberry Jam community have to transform their experience to fit with the regime, which for this particular example is not just about the technical competence but, as with all hackathon type events, is also competence in how ideas and technical skills are shared. Members of a community can also bring their wider experience to bear on the meaning of competence in a community if they have enough legitimacy as members.

I should point out here that as with the notion of a CoP generally, it is not straightforward to apply the notion of newcomers to a formal education setting. They are generally not newcomers to a practice in the way this term would apply to a professional work place, and in the latter part of this chapter I will look at the notions of tourists and sojourners that may help to explore these contexts.

5.3. A developing theory

In more recent work, Wenger has focused more on the general social theory of learning, of which a CoP is a core element. In 2009, Wenger highlights the constructs of knowledgeability, accountability and expressibility, the latter which subsumes but is broader than, the notion of expression we saw earlier through diSessa and Voloshinov. For Wenger, “participants must be able to express their experience of practice and who they are in that experience, so this can serve as the substance of learning” (ibid, p.4). Accountability is increasingly complex in a world where one has to decide which sources to be accountable to, where in this theory, knowing can be seen as the “modulation of identification among multiple sources of accountability” (2010, p.6). Further:

> “relations of accountability include what matters and what does not, what is important and why it is important, what to do and not to do, what to pay attention to and what to ignore, what to talk about and what to leave unsaid, what to justify and what to take for granted, what to display and what to withhold, when actions and artifacts are good enough and when they need improvement or refinement” (1998, p.81).

Expressibility, like accountability, relates to both practice and identity. A shared context with mutual engagement makes negotiation of experience easier, so for example two pupils who have experience coding in Python will be better able to discuss the potentiality of the RPi than those with no coding experience. An environment that enables participants to bring their broader perspectives to the practice, suggesting new ideas that arise through their multi-membership across boundaries, “is an important condition for the richness and meaningfulness of the inquiry” (ibid, p.5). This is reminiscent of Dewey’s standard of worth for social life, for communities, “How numerous and varied are the interests which are consciously shared? How full and free is the interplay with other forms of association?” (Dewey, 1916:1980, p.89). Expressibility gives us a construct that focuses attention on the fullness and freeness of this interplay. For school pupils, tools such as Boxer (diSessa, 2001) and Logo can enable teachers to make, for example, meanings of motion expressible for pupils who might otherwise have an experience of non-participation in the practice of being a science pupil.

A landscape of practice as a social body of knowledge, consists of many CoPs with “differential abilities to influence the landscape through the legitimacy of their discourse, the legal enforcement of their views, or their control over resources” (Wenger-trayner and Wenger-trayner, 2015, p.15). Within the Computing education landscape, just some of the practices that compete, overlap, and in any way influence each other that we have seen as stakeholders in the curriculum debate are: those within Computing based industries; Computing research in academia and in industry; the digital maker pratices; teaching and teacher training; educational research; studying at school, FE and HE level; and policy making in government. All of these interconnect with and influence other practices and broader landscapes, and all have their own regimes of competence. One practice may have more currency in a landscape than another, for example as we have seen Computing academia has had more currency than school teaching in the curriculum development, but this doesn’t mean that the more powerful practice can subsume the other. In the 'flatness' of the landscape, in the sense that there is "local knowing in each practice, whether or not this local knowing is recognized as knowledge in the broader landscape" (ibid, p.17) lies the possibility for change.

In a school, pedagogic practices relating to different subject areas connect to varying extents to each other and also across the boundaries of professional and academic practices relating to those competencies and this can be problematic: "Crossing a boundary always involves the question of how the perspective of one practice is relevant to that of another. It is connecting two forms of competence whose claim to knowledge may or may not be compatible" (Wenger-trayner and Wenger-trayner, 2015, p.18).

5.4. Knowledgeability and competence

Learning is a social becoming, rather than purely the acquisition of skills in Wenger's theory: "it is becoming a certain person - a knower in a context where what it means to know is negotiated with respect to the regime of competence of a community" (Wenger, 2010, p.2). In 2015, Wenger-Trayner and Wenger-Trayner define knowledgability in contrast to competence, as types of relation to a landscape of practice. Competence is what members of a practice are accountable to in a community, and the mix of experience and this accountability to the regime of competence, "constitutes someone's identity as a practitioner"(Wenger-Trayner & Wenger-Trayner, 2015, p.14). Competence is negotiated by the community and recognizable by it.

The increased focus on the construct of knowledgeability is in part to address the changing shape of what we call knowledge. These changes impact particularly on accountability, increasing the burden of the work of identification, where "there are an increasing number of locations in the landscape to which we may potentially need to become accountable" (Wenger, 2010, p.6), for example to the sources and types of information we pay attention to or contribute to, such as blogs, twitter feeds, discussion boards and so on. In defining knowledgeability against competence, "Whereas we use competence to describe the dimension of knowing negotiated and defined within a single community of practice, knowledgeability manifests in a person's relations to a multiplicity of practices across the landscape" (Wenger-Trayner and Wenger-Trayner, 2015, p.13). They go on to explain that, as the world is too big to know, we can't be competent in every practice, even within one landscape, but we can be knowledgeable about other practices in our landscape and their relevance to ours, which crucially, is part of understanding our location in the landscape (ibid, p.19). In this way knowledgeability is carried by trajectories of both practice and identity, which do not evolve in parallel, and Wenger claims "Learning takes place when they dance" (Wenger, 2010, p.7).

Knowledgeability in a landscape of practice then is a process of locating ourselves in that landscape. The modes of identification – engagement, imagination and alignment (see Appendix A) – are "ways to make sense of both the landscape and our position in it. All three can result in identification or dis-identification, but with different qualities and potentials for locating ourselves in the landscape" (Wenger-Trayner and Wenger-Trayner, 2015, p.21) which happens at multiple levels of scale. Wenger uses the example of a teacher who can identify and actively dis-identify with those in their local context and also on wider, national or global scales, also within disciplines (ibid, p.21). The combination of these modes of identification creates a nexus of identification and dis-identification, and Wenger asks:

> “how does this nexus of identification become a coherent experience of knowledgeability? … Knowledgeability entails translating this complex experience of the landscape, both its practices and their boundaries, into a meaningful moment of service” (ibid, pp.22-23).

As the process of locating oneself through modes of identification, knowledgeability “is an improvisational dance in which identification is modulated: in a given context, which sources of accountability to identify with and to what extent are these expressible? … To be fully realized, knowledgeability in a landscape requires that accountability to one location be expressible in another” (ibid p.25). But knowledgeability perhaps more obviously relates to adult practitioners rather than school children in a formal education setting, where the explicit practices of the institution are usually centred on abstract conceptions of knowledge or competence. So how can this construct be positioned to help understand the experiences of school children?

5.5. Tourists and sojourners

Fenton-O’Creevy, Brigham, Jones and Smith (2015) use the notion of tourists and sojourners in practice-based education to address this. They use the term imagined trajectory to describe how some participants may see their journey in a CoP as just a visit or passing through, as opposed to heading towards full participation (2015, p.44). In an educational setting, tourists may engage on the surface in meeting course requirements, whereas sojourners attempt to integrate their learning into their experience of knowledgeability, engaging with the meaning of the academic practice. This in itself may lead to varying experiences of participation and non-participation. The identity of visitors who only engage at a superficial level will not be significantly changed by the experience, and Fenton-O’Creevy at al refer to these as ‘tourists’. Visitors who, while still only intending to pass through, experience a high level of participation, “engaging with the meaning of local practices in ways which have implications for their own identity” are referred to as ‘sojourners’ (ibid, p.44). The identity work of a sojourner then will be “accommodation to the practices of that community and its regime of competence in order to function effectively within and beyond the community” (ibid, p.45).

Wenger shows that coordinating identities across regimes of competence can be burdensome work, and Fenton-O’Creevy et al use the notion of resilience to explore this. They suggest that, as identity changes across time and space, “a core challenge of identity work is the need to maintain a continuous sense of self in the face of threats to identity across landscapes and over time, and to manage the emotions this evokes” (ibid, p.45), and further, “Though persistence or continuity is foundational to any workable definition of self, we are not born with arguments at the ready concerning how we ourselves (or anyone else) ought to be understood to change and yet remain the same person” (ibid, p.51).

These are helpful terms to apply to learning in school settings, where the learning practices of young people relate to a particular regime of competence, and their core practice is being a school pupil. But in our siloed curriculum, each subject discipline can perhaps be seen as a practice at the boundary of formal education and the practices of which that subject discipline is a part, and thus has its own regime of competence. Pupils in KS3 are likely to be tourists, exploring new subjects and not necessarily mapping to future trajectories outside of the school setting. In most school settings it is in Y9, sometimes Y8, where pupils are potentially forced to consider their imagined trajectories as they decide upon options for GCSE examinations, and their participation as tourists will contribute to this. They may or may not become sojourners at KS4 or KS5, and their accountability to the regime of competence of whole school academia may or may not conflict with accountability to the regime of competence of the subject discipline.

The notion of knowledgeability gives us a framework to explore the identity work involved as pupils locate themselves, through modes of identification, within a landscape with respect to regimes of competence, as they participate and negotiate meaning within practices from their unique position as a nexus of multi-membership. As a continuous process of positioning themselves, it brings attention to the dynamic nature of the process, it is inherently emergent and works across levels of time and space, individual and collective. It encapsulates competencies for practice, without the need to create a duality of academic and vocational, or theoretical and practical, aspects of competence, while also foregrounding the notion of perspectives which Brennan and Resnick felt were all important but difficult to operationalize and to explore.

5.6. Learning citizenship – an ethical criticality

We saw discussion in the critical thinking literature around the justification for teaching criticality and whether it is in fact justifiable. There are questions over how we ask young people to critique the systems they live within, without totally undermining efficacy beliefs. Criticality is not something that is achieved and then retained, or that is naturally distributed across all domains, and according to Bandura and Freire, it is not something for which a curriculum can be prescribed. Rather criticality has to be seen as emergent within a given context, and therefore we need to design for and explore learning to understand how it might emerge. To do this, as Sfard’s work has shown, criticality then needs to be operationalized as an emergent, ongoing process, not an objectified abstraction.

In sympathy with a Deweyan view, Turkle and Papert refer to the work of Gilligan on moral reasoning to develop the ‘soft’ intellectual approach to Computing, considering contextual rather than abstract moral decisions. They say such an approach draws a focus on a mode of thinking, such that formal reasoning is a mode, not the stage of development that Piaget’s work would suggest. Wertsch (1991), drawing on Bakhtin, similarly suggests an alternative view of thought development as “heterogeneity without genetic hierarchy”, where different ways of thinking can be appropriate, or ‘better’ for different contexts. We saw in the literacy and criticality literature that there is some consensus that both constructs are domain specific, but this still leads us towards looking for certain ‘ends’ of thinking in certain practices, without taking into account the complexity of how those practices interact or that the very idea that there is an end goal of thinking is an act of objectification. It is a perspective that loses the temporality of experience, where even ideals are a representation of present circumstances, as in forethought which is "a present realization in imagination of future objective situations" (Dewey, 1922:1983, p.142) and where, the ideal becomes set up not as the "fullness of meaning of the present but a remote goal. Hence the present is evacuated of meaning. It is reduced to being a mere external instrument, an evil necessity due to the distance between us and significant valid satisfaction" (ibid, p.187). Yet as Whitworth (2010, p121) says, "Ideals still serve as means to criticise reality's failure to live up to them", and even Dewey acknowledges that:

> ""Idealism" must indeed come first - the imagination of some better state generated by desire. But unless ideals are to be dreams and idealism a synonym for romanticism and phantasy-building, there must be a most realistic study of actual conditions and of the mode or law of natural events, in order to give the imagined or ideal object definite form and solid substance …to give it, in short, practicality and constitute it a working end" (1922:1983, p.162).

In applying this temporality to the idea of criticality, to making judgments in action, which a Freierian perspective would say needs to lead to social action for 'good', Dewey asks "How shall thought which is personal arrive at standards which hold good for all, which, in modern phrase, are objective?" (ibid, p.56). Dewey claims Plato turned to the universal notion of reason which led to a transcendental ethics supplanting an ethics of custom. Dewey further explains that in times of rapid social change, objectifying ethics as transcendental and permanent leads to "disparity between nominal standards, which become ineffectual and hypocritical in exact ratio to their theoretical exaltation, and actual habits which have to take note of existing conditions" (ibid, p.58). He claims that this leads to a logic that we can only choose rationally among values if we have some fixed measure of values (ibid, p.166), which again stems from our need for certainty, and "a case of the wish for an intellectual patent issued by authority" (ibid, p.166).

Instead Dewey suggests questions of what is 'good' should be always momentarily based in current practice, in every act and every decision, through examining consequences. "Ends", goals or ideals are ends-in-view which are developed through consequences experienced previously, and which thus become possible future consequences through the work of imagination. They give added meaning and direction to acts but they are ends of deliberation and as such, pivots in action. Confusion over ends as "literally ends to action rather than as directive stimuli" (ibid, p.157) leads to confusion and, Dewey claims, "perversion of intelligence" through notions of 'the ends justifies the means' and 'meaning well'. In the former, one ignores the plurality of consequences inevitable in any act "in order that we may justify an act by picking out that one consequence which will enable us to do what we wish to do and for which we feel the need for justification" (ibid, p.158). In the latter, 'meaning well' is selected as the end, leading to a "sentimental futile complacency" (ibid, p.159) which doesn't accept responsibility for actual results. Every act is potentially one of morals, or judgements of value. Setting values as objectified entities takes the focus away from examining actual consequences and takes moral emphasis away from everyday acts. For Dewey, ethics is ongoing work:

> “Morals means growth of conduct in meaning; at least it means that kind of expansion in meaning which is consequent upon observations of the conditions and outcome of conduct. It is all one with growing. … In the largest sense of the word, morals is education. It is learning the meaning of what we are about and employing the meaning in action” (ibid, p.194).

He suggests that progress is an illusion from the perspective of attaining a good “that stays put … But we are looking for it in the wrong place” (ibid, p.198). Dewey advocates a focus on present good, found in a “present growth of significance in activity”. This suggests good is the “same in quality wherever it is found, whether in some other self or in one’s own. An activity has meaning in the degree in which it establishes and acknowledges variety and intimacy of connections” (ibid, p.202). Giroux criticised both functional economic and ideological approaches to literacy the latter which aim to “initiate the poor, the underprivileged, and minorities into the logic of a unitary, dominant cultural tradition” (1987, p.3). A Deweyian solution is to consider instead the welfare of others in widening and deepening “perceptions that give activity its meaning” rather than thinking in terms of “making people happy” as if we could hand this over as a physical thing, and so rather indulging “ourselves under cover of exercising a special virtue” (Dewey, 1983, p.202). Dewey suggests that social welfare as an end for action “promotes an offensive condescension, a harsh interference, or an oleaginous display of complacent kindness”. Instead, aiming: “To foster conditions that widen the horizon of others and give them command of their own powers, so that they can find their own happiness in their own fashion, is the way of “social” action” (ibid, p.203).

We’ve seen that the CoP theory draws attention to the journey of learning, our becoming, or our trajectories through landscapes of practice, a journey that incorporates the past and the future into our experience of identity in the present (Wenger-trayner and Wenger-trayner, 2015, p.19). Wenger’s notion of learning citizenship in concert with knowledgeability in a landscape of practice encapsulates the idea of expanding perspectives, widening horizons in which to find one’s own location and confidence in one’s own learning and learning opportunities, without objectifying, without losing the focus on the present.

Learning citizenship is an ethics of identity. Wenger describes how learning behaviour “can affect the learning capability of a whole landscape of social learning spaces. How we manage our participation in and across learning spaces is what I call “learning citizenship”” (Wenger, 2009, p.7). The quality of our engagement is something we are answerable for and affects our own experience and that of others in our learning space. Wenger situates this as an inescapable ethical dimension, because it is voluntary, “but with broad effects for individuals and collectives … People are going to act as learning citizens out of their own experience of the meaning and value of doing so” (2009, p.8). Learning citizenship works across practice and identity and as knowledgeability is locating oneself in a landscape, learning citizenship is taking responsibility for that unique location:

> "Learning citizenship is situated right at the crossroads between social learning spaces and trajectories of identity. As learning citizens, we proceed from who we are—our personal histories, connections, networks, vision, aspirations, and position in the landscape of practice—to find forms of participation that increase learning capability. When we seize opportunities to participate in social learning spaces, to bridge a boundary, to convene a community that needs to exist, it is because we understand the learning potential of our location in the world and act upon it … We can invest the perspective, capability, legitimacy, and accountability that we derive from our unique trajectory, where we have been, where we are going, and what that makes us. In this sense, learning citizenship involves a recognition that our identity, as a dynamic location in the social landscape, is a unique learning resource" (2009, p.8).

5.7. Summary

This chapter ends the exploration of the first research question laid out in chapter two, namely: How can we use a social theory of learning to frame the processes and outcomes of "criticality" in order to inform better learning design in Computing education? I showed in chapters two and three how the underlying theories and objectification of discourses around computational thinking has led to limiting and disempowering paths. The hegemony of the abstract and formal, dichotomies of abstract/concrete, academic/vocational and knowledge/practice are all perpetuated by current discourse. The criticality and literacy literature still tends to objectified categories and idealized ends. Although more recently notions of identity have become more prevalent in that literature, there is little in these approaches to account for developmental processes or the affective.

In Wenger's theory, learning is becoming through the interplay of identity trajectories within regimes of competence. It is a theory of emergent levels and processes, rather than transcendental ends. My research project then abandons the term criticality as also being: divided between logic or technocentric and literacy or ideological perspectives; questionable as an aspiration for education, at least at school level; and problematic to operationalize. Instead, Wenger's knowledgeability and learning citizenship provide constructs that focus attention on making connections, institutional structures, agency, efficacy, episteme and motivation, without prescribing "recipes", as Freire critiques (see chapter 3).

Wenger's framework allows us to consider competence, but exploring developing competencies is not the focus of this thesis. With such a new subject as Computing the research in developing computational competencies is also still in its infancy, and the learning activities explored in this project were aiming at developing competence, so in that regard it is discussed superficially in the analysis.

With Wenger's framework I avoid the technocentrism of asking questions such as: how does the RPi impact learning, or computational thinking, or grades? I can acknowledge that design in the service of learning Computing with RPi activities will be a complex process involving: practices on multiple levels - the school context, the curriculum, the classroom; and identities – the pupils, the teacher, the school management team. The design of a learning activity itself is a meaning making process. The response to that design, the learning, the becoming that happens during engagement that the designs initiate, will not map directly to any planned learning objectives in the designed activities. But nonetheless learning will happen.

I can situate the RPi as a boundary object, but not as a bridge between abstract and concrete, which simply perpetuates the notion that this division matters as anything more than an objectified discourse, but rather as a boundary object across multiple practices of academic Computing, electronic hobbyists, digital makers, and educationalists. As a boundary object, this project aims to explore specifically how learning design around the RPi might encourage growth in knowledgeability and learning citizenship.

With social learning theory we avoid also needing a categorical list of behaviours that might demonstrate a construct we call criticality to 'measure' against. The theory instead suggests we need to focus on identity in practice with temporality in mind. We are looking for where pupils locate themselves in their landscapes of practice at a given moment of time, and how this might change following the learning activities and to then consider whether these changes indicate growth.

The following chapter will introduce Q methodology as a basis for such an exploration, explain the adaptations of the methodology used in this project and describe the research project in practice through the four learning design scenarios investigated.

Chapter 6 - Q Methodology informing exploration of learning with RPi

"It had been easier to her to imagine how she would devote herself to Mr Casaubon, and become wise and strong in his strength and wisdom, than to conceive with that distinctness which is no longer reflection but feeling -- an idea wrought back to the directness of sense, like the solidity of objects -- that he had an equivalent centre of self, whence the lights and shadows must always fall with a certain difference." (Eliot, Middlemarch)

Introduction

In the previous chapters, a review of the research and theoretical literature has suggested a framework for the first research question of this project: a way to talk about the learning that happens in response to learning activities with a technological artefact, a framework based on a social theory of learning. In this project the educational technology being used is the RPi, in learning activities that have been designed to develop competence in Computing. This chapter describes the design of the research project, practically and methodologically, which aimed to demonstrate an exploration of the further research questions from this social theory perspective. In so doing, this chapter aims to justify the choice and further design of methodology as appropriate to that perspective. The following chapters then, focus on the research questions:

- How can the incorporation of Raspberry Pi technologies in learning design support growth in knowledgeability and learning citizenship?
- How can Q methodology be employed to explore the growth of knowledgeability and learning citizenship in pupils of Computing, and how can the methodology itself support development of these concepts?

In the previous chapter I described Wenger's social theory of learning which is based on our social becoming, the process of identification through practice. The constructs of knowledgeability and learning citizenship provide a way to capture aspects of what we mean when we talk about criticality, but with a more temporal ethics. The social theory of learning:

> "… claims that learning, thinking, and knowing are relations among people in activity in, with, and arising from the socially and culturally structured world. This world is socially constituted; objective forms and systems of activity, on the one hand, and agents' subjective and intersubjective understandings of them, on the other, mutually constitute both the world and its experienced forms" (Lave and Wenger, 1991, p.51).

Q methodology provides a way to explore agents' subjective and intersubjective understandings, and in the implementation of Q in this study, using a 'Before and After' model, changes in subjective position, the social becoming, can be explored.

The chapter will begin by providing an overview of the practical details of the project and a brief summary of Q methodology on which the research design is based. I will then look at Q methodology in more detail in terms of how it has informed this research project design and describe each stage of the methodology as implemented in this project. I will suggest how the research design is commensurate with the theoretical perspective suggested in the previous chapter and how it has been implemented in this project to explore learning in terms of knowledgeability and learning citizenship.

6.1. Project overview

How can the incorporation of Raspberry Pi technologies in learning design support growth in knowledgeability and learning citizenship? To explore this question, and embrace the unevenness of how the RPi might be used in different learning designs, the research took place at four secondary schools in the North West of the UK. Two of the schools were using RPis in class work and two in extra curricular clubs. These four different contexts are henceforth referred to as learning scenarios, and across the four scenarios, twenty-eight pupils participated in the study.

To explore developing knowledgeability and learning citizenship, the pupils were asked to demonstrate their perspective, how they located themselves with respect to the practices of Computing education, within their landscape of being a school pupil, before the learning activities with RPi and again afterwards. To do this, all pupils performed a Q sort activity, the details of which are explained in detail in this chapter. During the Q sorting process, where possible, pupils were encouraged to voice aloud any questions or doubts regarding the given statements as they engaged with the sorting activity.

Immediately following the second sort, pupils were interviewed in small groups of no more than four, during which they were given their original and second sorts to compare, and to reflect on any changes in their perspectives: to consider what the changes were and what aspects of their learning experience might have contributed to the change. These interviews were between forty minutes and an hour, depending on practical circumstances. I observed the work pupils did with the RPi as a means to understand what aspects of their activity they were referring to in these interviews reflecting on changes in perspective, and also to aid interpretation of data through situating the quantitative findings of Q analysis that presented shared perspectives. I additionally interviewed one of the teachers a few months after the RPi work, to explore how pupils were engaging with the subject at a longer time period after their initial RPi experience, and also to hear the teacher’s reflections on the activities. Unfortunately it was not practically possible in the other three scenarios to interview the teacher.

The process of Q analysis provides the shared perspectives across all participants, and this was used in conjunction with individual pupil sorts, interview and observation data to qualitatively compare pupils’ positioning before using the RPi and after, with respect to each scenario. The following sections describe the process of data collection through Q sorts, the supporting interviews and observations and the Q analytical process. The detail of each learning scenario in turn, which includes descriptions of the respective RPi activity, is given in the following chapter.

6.2. Q methodology: an overview

Q methodology was developed by William Stephenson (1935). Stephenson had two doctorates, one in physics, studied under doctorates from Ernest Rutherford’s laboratory (Stephenson, 1987), and one in psychology, studied under Charles Spearman. Stephenson’s work aimed to develop a science of subjectivity. Q methodology, which is a combination of a method of data collection and techniques for analysis, utilises approaches that would be considered qualitative and approaches that would be considered quantitative. This situates the method as controversial, as it is neither qualitative, nor quantitative, and there is debate among Q scholars as to whether it can even be considered as fitting the mixed methods paradigm (see Ramlo and Newman, 2011a and 2011b and Stenner, 2011).

In short, the methodology begins with a concourse, a set of statements that represents the communicability of a subject, from which a representative set of statements are selected. Participants take this set of representative statements and sort them into a grid with a normal distribution such as the one below:

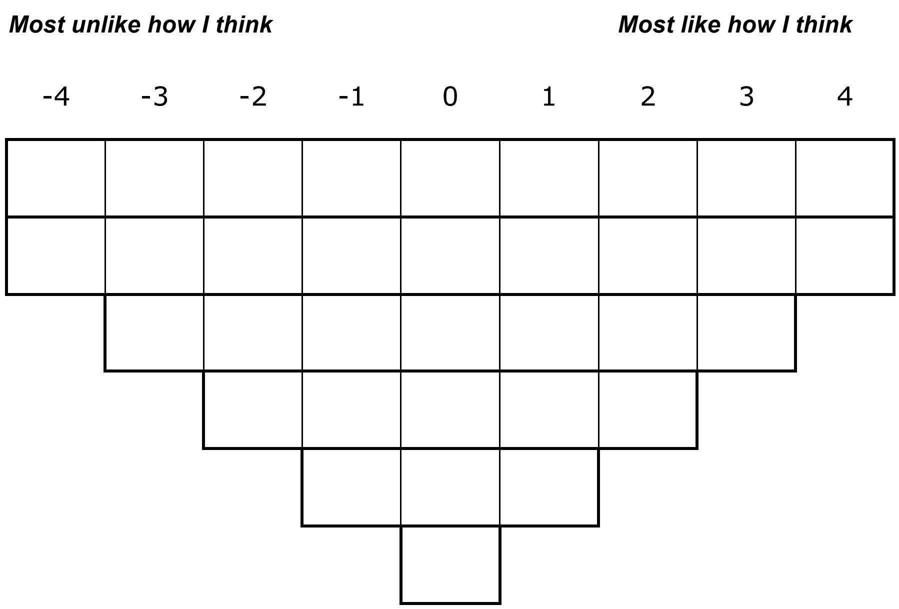

Figure 6.1. Q sort grid

The sorts are then correlated using factor analysis to find shared perspectives. Factors represent perspectives where there is consensus among participants. The factors, or representative perspectives, are then interpreted to describe what subjectivities exist within the topic area.

Ramlo (2005, pp.52-69) suggests that Q methodology has typically been applied in studies within politics and conflict management and rarely in education. Ramlo herself is a physics educator, and has done a number of studies using Q methodology for course evaluation (Ramlo, McConnell, Duan, and Moore, 2008) and learning episteme (Ramlo 2005, 2008), the latter which helped inform the concourse development for this study.

In the previous chapters, I have explored literature that advocates avoiding a dichotomy of individual or collective, and I believe Q methodology facilitates exploring learning in this way, working across both levels. This is also more appropriate from the perspective of an educator, who has to consider learning at both individual and class level. Similarly, with learning situated as a process of identity, as becoming, the methods needed to incorporate temporality. This project design then used a 'before' and 'after' model of Q methodology, but with qualitative rather than quantitative comparison of the two studies. Brown (1970), Cook, Scioli and Brown (1975) and Freie (1997) all use Q in an experimental design that involves comparison of Q studies involving the same participants at different time intervals, but all three focus on a quantitative comparison. In Brown (1970), the question being explored is whether participants have persistence in political ideology over time, so the comparison aims to see whether there is change, not what the changes are. Similarly, Cook et al (1975) explore whether watching a documentary has an effect on perspective, rather than what the differences in perspectives are.

Freie (1997) is the most similar model to this project, exploring the effects of campaigning on students' attitude to political activity, both in terms of whether there is change and what those changes are. Freie looks at which participants landed on a particular factor in the after study as compared to the before study, and he also compares the content of the factors to see how perspectives have changed. But his study still has an experimental nature, comparing before and after changes with experimental and control groups, and the detail of the campaigning experiences of these groups is unknown. In contrast, and where this project makes an original methodological contribution, is the focus on comparing before and after studies in terms not only of the movement of which participants land on which factors, but crucially the changes in perspective, both individually and collectively, are explored with reference to the contextual data from interviews and observations of the different learning scenarios. Additionally I ask the young participants to contribute their views to the comparative process. This enables an attempt to posit which elements of the context may have contributed to the changes.

6.3. Research design in detail

The design of my research project employed Q methodology as the starting point to explore shared perspectives, at two different points in time, relative to a learning activity with the RPi. This was done across four different learning contexts utilising the RPi. Participants within each context performed a Q sort before they had any contact with an RPi. Pupils were instructed to sort a set of thirty-four statements according to their views of Computing and what it means to them to be a student of Computing. All pupils knew when performing this sorting activity that they were going to be using RPis, but they had varying conceptions of what an RPi was.

In each context, the pupils then used an RPi as part of either a timetabled lesson in Computing (two of the contexts), an after school Computing club (one context) and a holiday club (one context). An outline of the scenarios in terms of the logistics of the project is given in table 6.1 below.

	Setting	*Age*	*Demographic*	*School type*	*RPi activity (see ch7)*	*Sessions observed*	*Time span between Q-sorts*
1	After school Computing club	Y8 - Y10	3 male, 1 female (from a mixed group of 6)	Secondary Faith Academy	Pi in Space	10 of 12	Two academic terms (Mar 2013 - Dec 2013)
2	Computing lesson	Y9	2 male, 4 female (from a mixed class of 21)	Secondary Academy	Sonic Pi	7 of 8	Just over one half term (8 weeks during April- July 2013)
3	Easter 2 day holiday club	Y8, Y9	3 male (from a group of 10 males)	Independent mixed school	Piface and Minecraft Pi	All	Three weeks (April 2014)
4	Computing lesson	Y8	4 male and 11 female (from a mixed class of 30)	Secondary Academy (performing arts specialism)	Sonic Pi	6 of 7	One half term (7 weeks, May – June 2015)

Table 6.1. Research design implementation by scenario

Observations took place during the activities where possible in order to represent the context of the practice as fully as possible, though this was not intended to be an ethnographic study and observation was mostly naturalistic, and based on participant observation. On some occasions the teacher requested some technical support and in these instances I acted essentially as a teaching assistant. But I was introduced to all classes as a student researcher from the University and all pupils were aware that the research sought to explore their perspectives on being a Computing student through working with the RPi. Observations explored in particular how the teacher supported pupils through the activities, how the activities were implemented, the environment in which the activities took place, and the interactions between participants. The observation schedule is shown in Appendix

D. All observations were audio recorded and notes were made using the schedule during and after each observation.

Either at the end of the activities with the RPi, or at a period of time that gave them appropriate time to engage with the activities, the pupils then repeated the Q sort. Immediately after this second sort was completed, the pupils were given their initial sort to compare in a reflective interview. They were asked to look for notable changes between their perspectives as represented by the Q-sorts, and to reflect on why they felt those changes may have occurred.

The analysis began with using the data as two separate Q studies: a ‘Before’ study and an ‘After’ study and the analytical process is described in more detail in sections 6.5 and 6.6 below. The Before sorts asked the pupils to provide their perspective on the subject and themselves as a student of Computing at a point in time shortly before experiencing the RPi. They were additionally asked to write comments on the statements they positioned at the extreme ends of the grid, explaining why they felt most strongly about these four statements. Ramlo (2005, p.61) explains that it is the statements at the extreme ends of the factor (those with the strongest z-scores) that most distinguish each factor. As is usual with Q sorts, pupils were also asked to voice questions or doubts as they performed the sort, although this was more difficult practically in scenario four, as discussed in the next chapter.

Pupils were providing a discursive snapshot of the process of identification, of locating themselves within the landscape of practice of learning Computing at school level. The Before Q analysis looked for representative perspectives or positions across all the pupils before engagement with the RPi. The After Q analysis then looked for representative perspectives after engagement with the RPi. Following the analysis of each individual study, these perspectives were then qualitatively compared at the collective level, to explore changes in representative views, or locations.

These perspectives were also explored at the individual level relative to the learning contexts. This analysis involved a comparison of Before and After sorts at the individual level, both to consider how the relative positioning of statements had changed for individuals with respect to the themes within the concourse, and to explore where individuals sat relative to the shared perspectives. For instance an individual may have loaded significantly on a particular shared factor - a shared viewpoint – in the Before study, but after engaging with their particular RPi learning activity, they may no longer have identified with any shared factor. Or where a change in perspective between the Before and After studies showed a similar group of pupils continuing to share a perspective, the analysis would highlight any pupils who moved between consensus groups. The interview and observation data was used to support consideration of what aspects of the learning design may have impacted on these changes at the individual level.

6.4. School sampling and ethical approval

Throughout this research project the RPi and associated technologies have been changing rapidly and there are practical difficulties using it within schools, not all of which have been addressed during the time frame. There are also broader practical concerns about the infrastructure available to teach Computing within formal education which are highlighted by use of the RPi, and this will be discussed more thoroughly in the analysis and discussion chapters. Consequently this study aimed to explore learning activities that a teacher had already planned as practically achievable, appropriate and of interest for their context and their pupils.

At the time when this study began, the RPi had only just been released and there were a very limited number of teachers using them. Schools selected for this research were approached through the STEMNet events and CAS hubs, which had offered their support and training events to all schools in the North West region. Schools A, B and C were the only three that had teachers who were planning on using RPis within the school that academic year. School A was the first in the North West to use them in a school context, although this was still an after school club rather than part of planned curriculum. The Sonic Pi resources were being developed in one classroom in Cambridge, and School B was the only other school in the UK trialling them, and ran two lessons behind the Cambridge school as the resources were adapted following each trial lesson. Two other schools began using the RPis during that academic year and agreed to be part of the study, however both teachers had to withdraw for personal reasons.

At this point, another school was needed, and in the following academic year a number of schools in the region were using RPis in numerous ways, including as part of an exam board task. As two of the three schools already in the study were using them in an informal setting, I was looking for another school using them within a formal lesson. As an RPi funded project, Sonic Pi had become an established scheme of work for using RPis in classrooms and was being used more and more widely, and School D wanted to use this for a term. Thus this school was selected purposively as an interesting contrast to the informal scenarios and to include the Sonic Pi design in a different setting.

This study received ethical approval from the University of Manchester’s ethical approval process. All pupils who were invited to take part in the study were introduced to the details of the study prior to their work with the RPi. They received information sheets on the study both for themselves and for their parents, and only those who returned consent forms signed by both themselves and their parent took part in the study and an example of this is in Appendix C. Teachers received equivalent information sheets and consent forms with respect to the observation of lessons, and teacher interviews, although only the teacher from scenario 2 was able to participate in an interview.

Within each school context, the pupils participating in the study were invited on a basis appropriate for the context. In school A, only six pupils were participating in the after school club, and in school C there were eighteen pupils in the holiday club, so all were invited to take part in the study. In school C, the teacher was interested in using the methodology as an evaluative tool for the holiday club, which was a new venture for the school, and so incorporated the initial sorting activity into the planned day, as a starter activity. In school A, five pupils accepted, but one pupil left the study before the After sort activity due to exam pressures. In school C, four pupils accepted but one of these was unable to complete the After sort.

In schools B and D, the classes were selected based on the teachers' plans with the RPi, as neither teacher intended to try using them with more than one class. For practical reasons, in school B the pupils needed to do the Before and After sorts and interviews within class and break times, so the teacher wanted to select the pupils to be invited, and suggested he would do this across a range of ability. In school D, the whole class was invited to participate in the study. The teacher was interested in the methodology being used for the project as a formative assessment method, and so incorporated the Before and After sorts into his lesson prior to the RPi activity, meaning all pupils in the class performed the sorts. Those who returned consent forms to take part in the study and whose first sort had been completed in such a way that it was usable were participants in the study. In total 28 pupils fully participated in the study, 12 male and 16 female.

In Q, sampling is more crucial in terms of the statement selection for the Q set than for participants, and the former process is described in the following two sections below. Sampling of participants, the P set, who in Q methodology represent the variables, should be "theoretically relevant to the problem under consideration" (Brown, 1980, p.192), and "… the design of P sets is intended to serve as a formula for purposes of selecting persons expected to have viewpoints pertinent to the problem under investigation … [in order to] maximize confidence that the major factors at issue have been manifested using a particular set of persons and a particular set of Q statements (ibid, p.199). Therefore the pupils selected needed to cover viewpoints relevant to learning Computing, through Raspberry Pi activities, as a school pupil. More detail regarding the individual pupils is relevant only because this project related the Q study data to contextual data, however this detail did not influence the sampling of participants for the study, so is given in the following chapter describing scenarios and in the analysis and interpretation.

6.5. Concourse development and Q sample (statement selection)

In this study the concourse was drawn from both academic and political literature, online communication and events involving teacher discussion through CAS, and interviews from my earlier MSc study on enquiry based learning in CS with first year undergraduate students. The statements selected for a pilot study were refined for appropriate wording, readability and coverage, in line with Paige and Morin (2014). The original list of statements and the developments made through the pilot study are shown in Appendix B.

The pilot study worked with two groups of five year 9 pupils from a small independent girls school and two groups of four year 11 pupils from a very large further education college to refine and develop the Q sample. In the former pilot group, the pupils did a Q sort before using RPis, and were interviewed afterwards and in the second group, the pupils performed the Q sort only after having worked with RPis and were interviewed in concert with the sorting activity.

A key aim of the pilot study was to ensure the statements were accessible to secondary age pupils and fully represented the concourse. Pupils needed to be able to relate to the wording of the statements and were also asked to suggest where there were aspects of being a student of

Computing that were missing from the statement set. This resulted in a number of amendments to the Q sample (see Appendix B). The pilot also tested the clarity of the condition of instruction and allowed the testing of practicalities of using Q sorts: for example space is needed to perform the sorts comfortably when using paper, and the number of statements selected needs to be appropriate for the demographic and the context. The condition of instruction for this study was:

"What do you think about the subject of Computing and yourself as a student of this subject?"

As a discursive methodology, not only exploring perspectives, but as a performance of reflection having the potential to affect those perspectives, Q sorting at the moment of its performance is inherently an imagined mode of identification (see Appendix A), as participants are asked to relate the statements to their identity at that moment in time. As a self-referential performance, the statements were worded to be deliberately self-subjectifying in line with Sfard's work (see chapter 4). The reification of self in these statements is relieved by the relative positioning of the statements during one sort, and the temporality of performing a second sort: although the sorter is in danger of objectifying or labelling their self with the given statements, which as Sfard (2008) explains is an inherent part of creating the narrative of our identity, the act of positioning a number of such statements relative to others and seeing how this can change over a relatively small time frame, emphasises that the reification is momentary, process-like, and thus is inherently agentic.

The statement selection also ensured there was mutually supporting comments, to aid interpretation. For example, statements 2 and 11 were respectively:

- (2) I think what I learn is more important to me than the grades I get
- (11) I think doing well in tests and exams is the most important thing in school

Rather than one statement being a negation of the other, which would be redundant, as the positioning of the statements within the grid indicates positive or negative identification with the statement, these statements are related in such a way that, in analysis, one would expect them to be positioned at relatively separate positions in the grid. Should they be placed close together, this would provide cause to question the sorter about this positioning of these particular statements as part of the interview. Statement groupings such as this, (see Appendix B for all groupings) informed the interview questions, along with the changes in positioning of individual statements between the Before and After studies.

6.6. Theming for selection and analysis

The statement set was selected as described above, to be representative of the communicability of school pupils with respect to their own position and experience of these practices, such that participants were enabled to manifest and express their relations to these practices through the sorting activity. The statements were themed for selection based on Brown's (1980) examples of structured Q samples. The themes used are discussed below. Brown explains that participants won't be able to distinguish statements that have been selected in a theoretically structured way from a randomly selected one, but “Structuring ensures balance (Brown, 1980, p.38), and so is recommended. He explains that this does not impact on how the participant’s perspective is manifested in the sort, as “theoretical rotation may produce a factor structure about which the original statement design has little to say” (ibid, p.39). The focus is not on what statements mean theoretically but rather “what the subject does with them operationally” (ibid, p.55). As Brown explains, this theoretical influence is what might differ between two samples using the same Q concourse, and this may “govern to some extent the way the data are gathered, analysed, and interpreted” (ibid, p.189). However, the “… virtue of structuring statement samples… is that it provides the investigator with the opportunity to state his theoretical position explicitly” (Brown, 1980, p.38).

Following the interviews and observations, the themes used to structure the concourse were reconfirmed with reference to this additional data, when interpreting the results, to incorporate as far as possible the participants understanding or use of the statements. So as an example, statement *(19) I think I can improve marks I get in all subjects through learning about Computing* is placed in the connection theme, but depending on the interpretation of the sorter, this could equally be seen as a statement about efficacy, whether it is possible to improve one’s marks at all. However in discussions with pupils, it appeared to me that they were mostly interpreting the statement as focusing on how Computing relates to other subjects in their academic context.

Wenger (2009) tells us that:

> “Learning in a social learning space covers all the aspects of knowing relevant to a person who can act meaningfully and competently. This accountability to identity includes ways of being, behaving, and talking. It involves issues such as efficacy, legitimacy, values, connections, and power, typical of engagement in the human world” (2009, p.4).

The themes that emerged from the concourse development were based on these aspects of knowing: efficacy and legitimacy; ways of knowing; values and learning citizenship; and connections. The statements indicated accountability in relation to levels of self, school and subject, so the final theming suggested a matrix of themes and levels, as indicated by table 6.2.

The *efficacy/legitimacy* theme appeared in statements around pupils’ perception of their competence and understanding in the subject, and how they interpret, and believe they are able to align with, the regime of competence of Computing and of being a student of Computing. In relation to self, this appeared as statements about a sense of efficacy as a learner of Computing: whether they can program, teach others how to program, build devices and how they position themselves relative to others in the landscapes of Computing as they experience and imagine them. It also included in relation to school, statements about their beliefs of how others might perceive learners of Computing, and so in effect, how they felt others may impact or perceive them in terms of their efficacy and legitimacy. With respect to the subject, the efficacy statements included those about the perceived difficulty of the topic and aspects of practice they perceive to be required for an inward trajectory.

	Efficacy/legitimacy	Ways of knowing	Values/Learning citizenship	Connection
Self	(1) I think I know how to program a computer (4) I think I could build a device that controls something (7) I think I could teach somebody else how to program a computer (22) I think I have a good idea of what I want to do after I leave school (13) I think I know more about computers than most people my age	(16) I think I can improve how I learn about computing (32) I think I learn more from the teacher telling me things than from doing the activity	(23) I think if I write a program what is most important is that it works correctly (25) I think if I write a program what is most important is that it helps somebody (24) I think I am a good student	(8) I think I will use in the future what we are learning (10) I think I understand how the technology I use every day, like my mobile phone, works (17) I think learning about how computers work is really important for my future
School	(30) I think when we work in a group we learn from each other (21) I think people who are into computers are seen as geeky (6) I think friends who haven't done this activity would/will be impressed to hear what we are doing	(2) I think what I learn is more important to me than the grades I get (11) I think doing well in tests and exams is the most important thing in school (31) I think that people can learn to program in their spare time without a teacher	(14) I think others think I am good at working in a team (33) I think I learn more when I am helping other people to do things (28) I think my friends or others in my group learn from me as much as I learn from them	(5) I think I can see how what we are learning will is relevant to other subjects I study at school (19) I think I can improve marks I get in all subjects through learning about computing
Subject	(20) I think computer science is a really hard subject (34) I think being a computer scientist means being good at talking to people	(29) I think that anyone can learn to program (12) I think computer science is about building computers (15) I think computer science is about making software (18) I think computer science is about solving problems	(3) I think people who can program computers are more powerful than those who can't (9) I think people who make and program computers can make the world a better place	(26) I think computer science is like maths and physics more than it is like history, sociology, citizenship (27) I think being able to use computers in lots of ways is more important than being able to program them

Table 6.2. Statement coding

Ways of knowing, in relation to self and school, included generic learning beliefs, although the condition of instruction asked that the statements were positioned in terms of the subject domain. These statements included the possibility of improving learning ability, learning processes such as working in groups, teacher transmission of knowledge, and accountability to the process of learning and to the regime of competence of school practice, i.e. to assessment mechanisms. In relation to subject, the statements include those that relate to: learning episteme - whether they perceive the subject as being for 'academic' pupils or for all; and domain episteme – whether they perceive the core of the discipline to be hardware or software focused, or rather on a focus more related to use - problem solving.

The *values/learning citizenship* theme in terms of self appeared in statements around their priorities for the activity of programming and their perception of themselves as a 'good' or 'bad' student. The selected statement for the Q sample of "I think I am a good student' worked in terms of where it was placed relative to others that incorporated aspects of learning citizenship, such as whether they felt others were able to learn from them, and helping others in group work. In relation to the school level, values came out in statements around how they perceive themselves to invest in their learning community, and with respect to subject, the statements were about how domain competency might enable a contribution to society.

The *connections* theme at the level of self included statements around the perceived relevance of the learning activity in Computing to their future and to their life outside of school, to their imagined trajectory. At the school level, the statements included an awareness of links between the competencies being studied in Computing and other domains, and similarly links between the perceived learning skills for the subject of Computing as relevant to other domains. In terms of the subject level, the statements included those that explicitly situated Computing in relation to natural and social sciences, and perceptions of the nature of the subject in terms of the aims posited as CS and IT by the curriculum.

6.7. The Q analytical process

There are a number of tools available to perform the statistical analysis aspect of Q, which looks for factors that represent consensus in perspective. PQMethod was the tool used in this research project. This tool allows the researcher to take the sorted statements as numerical data, in terms of their relative position within the grid, and then to extract factors via centroid or principle component analysis techniques.

Watts and Stenner (2012, chapters 5 and 6) explain the conceptual basis for Q analysis, the main points of which I will summarise here. A factor is like a slice of cake, and any cake can be sliced in a huge number of acceptable ways. The data can suggest ways to 'cut the cake', an approach that would be associated with exploratory factor analysis (EFA) but equally the researcher may have reasons based on additional data for taking the lead in decisions on how factors are extracted, an approach that would be associated with confirmatory factor analysis (CFA).

Watts and Stenner (ibid) explain Spearman's factor analysis with the example of a table of participants who may have taken a series of tests, memory, verbal ability and so on, and have a score for each of these tests. Factor analysis could be used to reveal patterns of association between the variables of these test scores. In order to correlate the variables, which may not use the same unit of measure, the scores are standardised. This is done “by calculating its [absolute score] relative position within an overall distribution of gathered scores” (2012, p.9), allowing distinct variables to be directly compared (ibid, p.10). In the example, an “association between verbal, mathematical and problem-solving ability” could perhaps be understood as a factor of *intelligence*. Thus traditional factor analysis reveals “associations and differences *between variables* mapped at the population level” (ibid, p.11), but doesn’t tell us about individuals.

Correlation in Q “provides a measure of the nature and extent of the relationship between any two Q sorts” (ibid, p.97). A correlation matrix contains the relationships “*between all the Q sorts in the group* or, in other words, the relationship of each Q sort with every other Q sort” (ibid, p.97) in the study. The matrix of all the sorts or perspectives and their relationships represents “100% of the meaning and variability present in the study” (ibid, p.98). Factor analysis is a data reduction technique that aims to identify common or shared meaning in the data. The factor extraction process then, is the “identification and removal of distinct portions of *common variance* from the correlation matrix” (ibid, pp.98-99).

Q is based on a shift from by-variable to by-person factor analysis (ibid, p.12). The simple way to do this is factorisation by rows instead of columns, but although this transposed matrix model is often the one used in text books, it is not the method Stephenson developed. Instead Stephenson’s method involved a different form of data: traditional factor analysis usually associated with R methodology uses data “derived from a population or sample of individuals each of whom has been *subjected to measurement*“ (ibid, p.15) whereas Q methodological data is “derived when a population or sample of tests (or other items) are *measured or scaled relatively* by a collection of individuals” (ibid, p.15) The data is standardised through the nature of the data, rather than mathematically (ibid, p.16).

Once factors are extracted, they can then be rotated by hand or through varimax. Ramlo (2016) argues that the theoretical aims of Stephenson’s work would suggest that centroid extraction and hand rotation are the ideal choices. From the quantum perspective that Stephenson’s physics background gave him, centroid extraction makes sense because it does not provide one best solution, (ibid) but rather allows the researcher to apply their knowledge of the context and their participants to determine how many factors are extracted.

Hand rotation positions the researcher at the centre of the process (see Ramlo 2006, and 2008). In this study, I used centroid extraction followed by varimax rotation, but then used the factilities offered through PQMethod to hand rotate the factors where appropriate, detailed in the analysis chapter, a strategy that was informed by Watts and Stenner (2012, p.126-127). Watts and Stenner (2012, chapter 6) explain how rotation provides different viewpoints through which to observe the data. But whatever method of rotation is used at this analytical stage, Ramlo emphasises “the interrelationships of the sorts are fixed by the sorters themselves, via their Q sorts. Rotation only serves to change the axes and does not rotate the sorts” (2016, p.79).

The resultant factors are representative perspectives, and will show which sorters views are very similar to it, which participant perspectives correlate highly with this perspective. The data also shows consensus statements across the factors, agreements within the participants that can be a starting point for commonality. These factors are “an exploratory means rather than a reification of an entity through proving the existence of a factor. They are a thinking tool for the scientist to ask, ‘What, in other words, must subjectivity be like, if such and so are the factors?’” (Wolf, Good and Brown, 2011, p.68).

Thus once the factors have been determined, they are then interpreted and this has historically been a less structured part of the methodology in many cases. However, Watts and Stenner (2012, p150-164) have developed systematic interpretation guidance that was followed in this project. The interpretation following this method is a description of the perspective as closely as possible to a first person description, ensuring the voice of these participants is fully represented and, at this stage only, keeping the researcher influence as objective as possible.

6.8. Implementing Q – practicalities in classrooms

Through the pilot study, it appeared that thirty four statements was appropriate to encapsulate the necessary themes while remaining not too onerous for pupils who might have to perform the sort during class time, or too daunting when performing such a reflexive activity. Newman and Ramlo suggest that the number of statements is key to Q methodology where, “researchers must have a sufficient number of items to determine differences among the participants, not a sufficient number of participants to determine differences among the items” (Newman and Ramlo, 2010, p.508). The grid layout was chosen to aid the sorting activity, and to put emphasis on just two statements at the extreme ends of the grid, which pupils could provide written comments on where interview time was limited. As shown in fig. 6.1 above, a distribution from -4 to +4 was used.

In all but one context, the pupils performed the sorts with a paper based resource, having a card or paper based grid and strips of paper containing the printed statements. They sorted these strips into three piles, ‘most like’, ‘least like’ and ‘neutral/unsure/ambiguous’, and then placed them onto the grid starting with the extreme ends. They then wrote the number corresponding to the statement into the grid. In school D this was problematic because the whole class was participating in the sorting activity, and the layout of the classroom in which the activity was taking place had desks where the keyboards and monitors took up the majority of the available space so there was no place for placing the grids and statements.

Consequently an implementation of FlashQ was used for this group (see Appendix E for screen shots). This online tool follows exactly the same process for the sorting activity, but on screen. Participants are shown each statement in turn and then drag and drop them into three piles. The next screen then shows the grid into which participants are asked to drag and drop the statements from the piles. They are given the opportunity to amend the grid before answering any additional questions. In this scenario, the pupils were asked to enter comments on the extreme positioned statements, as in the paper-based sorts.

6.9. Knowledgeability and the ethics of Q

The construct of knowledgeability was introduced in the previous chapter as central to a social theory of learning that has a "dual focus on practice and identity [that] has to manifest in two ways: in the accountability of learning to the experience of participants (the lived experience that learning needs to enable) and in the expressibility of experience (how the actual experience of participants can become engaged in the learning process)" (Wenger, 2009, p.4). People need to be able to express both "their experience of practice and who they are in that experience" (ibid, p.4). Q methodology is inherently about expressibility of a perspective at a given moment in time, and the Q sample for this project was drawn along themes of accountability to identity across the practices of school Computing.

The Q sample then aims to discursively represent the landscape of being a school pupil of Computing, that enables pupils to perform an orientation with respect to this landscape at a brief moment in time and thus to provide a snapshot of identification. The observations aimed to capture aspects of the practice and the pupils' engagement with the learning activity particularly, and the context more generally, as tourists in most cases but possibly also as sojourners, depending on their imagined trajectories (Fenton O'Creevy et al, 2015, p.44). Sojourners were more likely to be found in scenarios 1 and 3 as these were voluntary activities. Observational data provided context to refer to in attempting to interpret the participants' meaning making process around the Q sort and the reflection on the sort comparison.

In the analysis I looked for developments in knowledgeability and learning citizenship in terms of how the orientation was performed after the learning activity, situating the sorter in a different location – a different sort – or with different construction of meaning around the same statements. The observations and interviews provide data to explore what elements of the learning design might impact this orientation. I made no inherent assumptions here about growth, or what would define growth before starting the analysis. There was no desired end point or assumption about what would constitute 'good' or 'better' knowledgeability, there is only, consistent with both Q methodology and a social theory of learning, an assumption that change is likely and worthy of exploration and interpretation in retrospect.

As already mentioned, the process of performing this orientation is a reflexive act. In chapter 3 I showed reflection was a focus in the literature around criticality. While an experience of knowledgeability wouldn't necessarily include reflexivity, in order for knowledgeability to develop, for a pupil to expand their horizons with regard to their relations to the multiplicity of practices in a landscape, I have presumed reflective practice would be helpful. Explicitly asking pupils to reflect on a comparison of their sorts, encourages them to take a reflexive, developmental and agentic view of self, of their orientation in their landscapes. Ramlo (2006) and Stephenson (1988) relate this aspect of Q sorting to quantum physics where the measurement affects the person being studied. This is "to be celebrated and used appropriately to address a variety of research purposes" (Ramlo, 2006, p.84). In the case of this project, I saw Q methodology as supportive of the question under consideration, to potentially help pupils develop reflexivity and awareness of their own knowledgeability and learning citizenship with respect to the landscape of Computing education.

In the previous chapter I suggested that the affective is backgrounded in critical thinking and literacy literature, but as a methodology, Q inherently includes this. Deignan explains:

> "William Stephenson, Q methodology's originator, drew on Peirce to emphasise the importance of subjective feeling in the formation of meaning and likewise in Q-sorting, where 'feeling is primordial' (1980, p.9). The correlation of individual values and meanings, as modelled in participants' Q-sorts, is at the heart of Q methodology" (Deignan, 2013, p.120).

Q is an inherently democratic method, as no sort is given higher status than another. Through development of the concourse, all elements of viewpoints relevant to the context should be included. Deignan goes on to explain that:

> " … with Q methodology, by completing and subjecting their respective Q-sorts to correlational and factor analysis, a university student's voice may be given the same weight in mathematical Q factor space as that of a support tutor or a government education minister. In this way, diverse stakeholders' views and the logic of their respective belief systems may be included, compared and contrasted, and weighed in the balance in relation to decision making on policy and practice issues" (2013, p.120).

Some critiques of Q question the finite number of statements and researcher selected number of factors as suggesting the possible perspectives to be represented are limited (for example, Kampen and Tamas, 2014, pp.3109-3126). However as Brown (1980, p.265-267) demonstrates, with a statement set of thirty three, there are over forty four trillion possible arrangements of the statements. The extracted factors show only the shared perspectives and this allows for considerable agency in one's orientation with the Q sample. I believe that my implementation of Q speaks to Freire's concerns of:

> "… the fundamental recognition of the people's right to be the subject of research that is attempting to know them better, not the object of research that specialists do around them. In the latter case, specialists speak about them; when there are many specialists, they speak to the people but not with them. Specialists only listen as long as the people respond to the questions specialists ask. It is clear that this kind of research demands a methodology outside the scope of this discussion, a methodology that implies recognition that the people should be the subject of the knowledge about themselves" (Freire and Macedo, 1987, p.46).

6.10. Learning citizenship, identity and the ethics of Q

Q also intrinsically promotes the notion of learning citizenship in that, through a reflexive act related to both their formal education and their learning, participants are positioned as in a unique location in space and time and as answerable for that location (Holquist, 1990, pp.149-170). In the reflexive interviews comparing Before and After sorts, participants are explicitly expected to answer for their learning. The notion of answerability from Bakhtin, (1993) also fits well with Q methodology and Holquist suggests, "dialogism is very close to the thought of C.S. Peirce" (1990, p.50), whom Stephenson drew on in developing Q. Holquist describes Bakhtin's "science of ideologies, the study of differential relations between "I" and others, where the meaning of "other" may range from other individuals, through neighbourhoods, classes, professions, etc., all the way up to other culture systems" (ibid, p.50). Bakhtin describes these notions of "I" and others as:

> "… two value-centers that are fundamentally and essentially different, yet are correlated with each other: myself and the other; and it is around these centers that all of the concrete moments of Being are distributed and arranged" (ibid, p.74).

A Q-sort provides a snapshot of a moment of identification with respect to a particular (subject domain referent) slice of multi-membership, and the analysis provides the opportunity to explore this slice with respect to the value-centres of the participants, and of their position with respect to each other. The temporal use of Q methodology with accompanying observations in the design of the research project aims to address Papert's concerns that:

> "It is a self-defeating parody of scientism to suppose that one could keep everything else, including the culture, constant while adding a serious computer presence to a learning environment. If the role of the computer is so slight that the rest can be kept constant, it will also be too slight for much to come of it" (Papert, 1987b, p.8).

But the method goes further than addressing technocentrism, and also addresses some of the concerns raised by Sfard and Freire whose work was explored in the previous chapters. Sfard claims that as a methodological construction, "To make the notion of identity truly useful in answering the outstanding questions about human development, we need to be more knowledgeable about the mechanisms of subjectification" (2008, p.292). In the use of Q in this project, self-subjectifying statements are provided, but participants own the meaning of these statements for their sort, and have the opportunity to conscire[1], self-referentially, what this meaning is through the sorts and associated interviews. As Voloshinov describes, language moves between processes, not essentialities, of subjectifying and objectifying:

> "In each speech act, subjective experience perishes in the objective fact of the enunciated word-utterance, and the enunciated word is subjectified in the act of responsive understanding in order to generate, sooner or later, a counter statement" (1973, p40-41).

[1] As Sfard uses the term commognition to encapsulate the language-based nature of thought, Stephenson used the term consciring, "sharing of knowledge", from the Latin *conscious* (Stephenson, 1982). Wolf et al describe this as "an intersubjective conception of knowledge" (2011, p.64). Stephenson explained that this takes two forms, "one with self-reference and one without" (1982), that the former is informational and the latter communicative (1980) and suggests that Q be regarded as "an operational basis for the study of language in relation to feeling and self-reference" (1982).

Finally, as a science of shared subjectivity, implemented with temporality and across levels of individual and collective, I believe my use of Q methodology addresses Freire's concern, (see section 3.8) with individualistic approaches that negate subjectivity and deny human agency (Freire, 1987, p.58).

In the next chapter I will describe each of the four learning scenarios in detail in which this implementation took place, before describing the analysis in detail in chapters 8 and 9.

Chapter 7 – The Learning scenarios

“Sufficient breadth can be its own kind of depth” (Weinberger, Too Big To Know)

Introduction

This chapter describes in detail the contexts of each learning scenario centred on the RPi tool. This context information then informs the analysis of data in justifying interpretations of factors, and comparing the Before and After studies to infer which aspects of the scenario may have been influential in changes in perspectives of the learners.

7.1. RPi constants

All four scenarios used the same version of the RPi, the model B version. The first two scenarios used early versions of the Raspbian operating system and the latter scenario used a later version of NOOBS, which ran faster than previous installs, particularly when using Scratch but also for Sonic Pi. All scenarios involved almost identical physical set up: disconnecting monitors, keyboards and mice from the workstations that were permanently placed in the spaces in which pupils were working; connecting these instead with the RPi board; connecting the power cable and inserting an SD card containing the OS and other software. The handling of the kits for scenario 1 was slightly different, in that only one board was being used but with several peripherals such as a web cam, and in the remaining three scenarios, kits of an RPi board, power supply and cable, SD card, monitor cable and adaptors were stored either in boxes or bags and were numbered for pupils to collect the same kit at the start of each lesson.

7.2. Scenario 1 – School A

The Head at School A had been very supportive of the move from ICT to Computing and a GCSE option in Computing was already available and being taken by one class at the time of the study. The numbers selecting GCSE Computing doubled during the year the school was in this study. The Head and the Computing teacher had a very good relationship, and the teacher was encouraged to be involved in supporting other schools to develop their Computing provision.

The Computing teacher who took part in the study, who was the Head of department, had a background in software engineering followed by a number of years teaching ICT but with considerable focus on the broader Computing elements, including coding. He appeared pleased with the curriculum changes and attended many events in the area to connect with other Computing teachers and to share his own experiences. The School agreed to take part in the study at the start of the 2012 academic year, which was the point at which the ICT curriculum had been disapplied. The previous academic year, the teacher had been using the MIT Scratch Creative Computing curriculum with his KS3 classes, and Y9s had also done some Visual Basic programming.

The teacher had already bought some RPis for an after school club before attending the STEMNet event at which attendees were invited to take part in this study. The intention was to provide a club for a small group of enthusiasts who had expressed an interest in taking the GCSE, in which they would attempt to emulate the 'Pi in Space' project undertaken by an electronic hobbyist and documented online. The aim of the project was to use a RPi to control a webcam which would be launched into space using a small balloon and relay photos back to Earth during the ascent. It would also record the altitude reached, and continue to do this once the webcam failed due to the low temperature.

The teacher presented the aim of this project to potentially interested pupils, but intended that they would lead the project themselves. There were no formal learning objectives given for the project, other than to engage the pupils in something more creative, 'hands on' and challenging than they were experiencing in lessons. The teacher told me it was also a project he was really interested in and keen to do from a personal perspective.

The after school club took place in the teacher's usual classroom, straight after the end of the school day and usually lasted for around forty five minutes to an hour, depending on the pupils' other commitments. The classroom was relatively small and arranged with 28 machines in total, placed around the edges of the room with a double row through the middle. The monitors in the classroom were DVI so converters were needed and there wasn't a great deal of working space around the monitor and keyboard.

Six pupils participated in the club over the lifetime of the project. The core group included two girls, both from Y9 and three boys, two from Y8, and one from Y9. In addition another Y9 boy attended intermittently, mostly during the coding phase of the project, but only for a few weeks in total. All six pupils participating were considered high achievers at their level in the school, the Y9 boy, 1A[2] exceptionally so.

Of these pupils, the three boys and two girls all agreed to participate in the study, but one girl, who will be referred to as 1E, was unable to complete the final Q sort. This girl did plan to take Computing as an option, but was interested in the subject more from a business perspective. The other girl, who will be referred to as 1D, was not sure about whether Computing would be one of her GCSE options, but was very keen on electronics and certain she would take that subject. She was attending the club specifically with an interest in the electronics aspects of the project. 1A was already taking Computing GCSE and was in his first year of studying for this. The Y8 pupil 1C, spent a considerable amount of spare time playing with code, particularly Scratch, and had been working with the other Y8 student, 1B, on an extensive space invaders game. When the club sessions weren't going as planned because the coding was proving particularly difficult, or the teacher was delayed, or they were waiting for some equipment, 1B reverted to working on his game.

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[2] . Individual pupils are referred to by codes that relate to their Q sort data, shown in table 8.1 in the following chapter

The project began with a few weeks of research, during which pupils explored the available information about similar projects, looked into what equipment would be needed in addition to what they already had and placed orders for this with the teacher's support. They discovered that they would also need to apply for permission from the national aviation authority to launch their balloon with the RPi device. For this they needed to consider other air traffic patterns and an appropriate launch location, use data on weather and wind speeds to predict the height reached and distance travelled, and plan for tracking the device to collect it on landing.

The teacher did not intervene unless asked. The pupils decided each week what they needed to do to progress. During this period, one of the school's science teachers was consulted. He provided an informal session to the Computing teacher and two of the boys on how they could perform the measurements required to estimate the size of the balloon needed and the launch calculations to consider, given the weight of the elements which would go into the device, such as the RPi and the webcam.

Once the pupils had ordered the parts for their device, they began to look into the coding requirements. Only one of the pupils had a small amount of experience using Python, but the three boys and 1E had done quite a bit of coding in other languages and were familiar with basic principles. They primarily reused pieces of open source code available on forums from hobbyists doing similar projects, and integrated it into their own code. At the same time, the pupils began to look into the process of actually building the device and the teacher requested support from a STEM ambassador through the STEMNet regional team. An electronic engineering Masters student from the neighbouring university spent a couple of sessions with the pupils, including one in the DT lab looking at soldering elements onto a breadboard. During this period the group had begun to split into two subgroups, by gender, with the boys doing more coding and the girls focusing on the application for launch and the device elements, but 1D was particularly engaged in this electronics session and she appeared to enjoy demonstrating some techniques to the boys.

The aim was to launch the device before or after the Easter break, but the pupils hadn't managed to complete the device due to a delay in receiving parts from one of the manufacturers. This coincided with a particularly busy period for all of the pupils, four of whom were doing a Duke of Edinburgh award in addition to their studies and needed to attend meetings for this on the same day as the Computing club during the summer term, so only one or two pupils attended during this period and the momentum of the project tailed off.

In July, the pupils were asked to attend a RPi workshop for local teachers as part of a Google funded project where RPi kits were being sent to CAS hubs. They gave a short presentation in which each of the five pupils who had been most involved described part of the project. This was delivered to a room with thirty-eight teachers and was followed by a question and answer session that lasted nearly thirty minutes and included some quite difficult technical questions. The pupils were all able to answer questions equally, and really engaged in conversation with the teachers. Anecdotal feedback from the School A teacher following this event suggested the pupils had really enjoyed the experience, despite being very nervous beforehand, and the teacher felt their confidence had been boosted, both in the subject and generally.

During the following academic year, the teacher did mange to arrange a launch but this failed due to an inaccurate calculation and the balloon bursting. But some months later the device was launched successfully, and unfortunately none of the original group of pupils were able to attend. They did however get to see the video relayed back. At the time of writing, the teacher is involved in a funded project to write up the details of the project as a package that other teachers can use in similar clubs.

In this scenario, the Q sorts were done on paper, and discussed face to face in an informal interview both for the before and after sorts. All five committed pupils agreed to participate, but 1E was unavailable to complete the after sort. The 'before' sorts took place on the second week of the club, at which point four of the five committed pupils had seen an RPi but not used them. 1B had an RPi of his own at home, but had done very little with it. The 'after' sorts took place at the end of the calendar year, when the club had not met for several weeks and the pupils' planned launch had been cancelled.

Practically, the pupils used a large A3 card with the grid outlined and the statements were provided as stickers to be placed on the grid. This was possible in this scenario as there was an adjacent room to the classroom with large tables for working space. During the first sort, the pupils were asked to think aloud while placing the statements and were also asked about the statements that they placed at the extreme ends of the grid. They did not find thinking aloud easy and were prompted both during and after to explain their understanding of the statements and their reasoning for placing them in a particular position. Following the second, 'after' sort, pupils took part in individual interviews where they were shown their first sorts and asked to note any differences, particularly where statements had moved two or more columns from the first sort. They were then asked to consider why their views might have changed, principally with reference to elements of the RPi project.

7.3. Scenario 2 – School B

The Head of School B had relatively little to do with the Computing department that was run at the time by one of the Assistant Heads. The Computing department had a strong background in CS, with two male members of staff both having degrees in this area. The Assistant Head was responsible for IT and technology enhanced learning across the curriculum, and there were an additional two members of staff who taught across business and maths in addition to Computing. These latter three appeared to work closely with the other two members of staff and all taught Computing lessons that incorporated aspects of CS. The Assistant Head saw using RPis in the school as a demonstration of their commitment to incorporating new technologies into their teaching. All pupils in KS3 did one hour per week of Computing, but this had been mostly IT based in Y7 and Y8. The RPi activity took place in the summer term, by which point the pupils had done a number of weeks working with Scratch, plus a term on Visual Basic projects.

The Assistant Head (Teacher B) was the teacher that used the RPis as part of this study, although it had been one of the other teachers that had originally expressed an interest in being involved in the study. Teacher B was the only teacher in the study that also agreed to be interviewed in the term following the RPi lessons and was then actually available to do so. He had an extensive background in education and had recently completed a PhD in educational leadership.

This teacher wanted to use the Sonic Pi activity, which was under development at the time. Sonic Pi is based on a programming language called Ruby, and was created by Sam Aaron, a CS researcher based at the University of Cambridge whose PhD thesis had incorporated elements of his interests as a musician. He is a live coder, which involves creating music as a live performance but where the music is coded, or is a combination of computer and acoustic instruments. He was funded by the RPi foundation to create a set of activities for school level Computing lessons based around coding music, and Sonic Pi was the language and programming environment developed to achieve this. At this stage it was developed purely for the RPi platform, although subsequently it became available also on more standard platforms such as Mac and Windows. The pupils in this scenario used a very early version of Sonic Pi, which has subsequently changed dramatically, and options such as different sound effects and volume were very limited at the time this project took place.

In collaboration with a teacher in a local secondary school, the resources around the language were a set of five lesson plans, using a standard pro forma that described learning objectives, starter, main and plenary activities, and necessary resources. The lessons were entitled:

1. Getting started with Sonic Pi on a Raspberry Pi
2. Debugging and iteration
3. Conditionals and randomisation
4. Data structures
5. Concurrency

As the resources were being developed at the same time as this school was using them, it meant that the teachers were only able to see each lesson the week before they needed to deliver it. After the first two lessons the teacher decided to repeat some elements of the first two lessons and this gave more preparation time for the remaining four lessons. He also planned a final lesson where the pupils would play with the software and using the concepts learnt, would create a piece of music in an informal competition with their peers.

Using the RPi with a full class in timetabled lessons created practical issues that the teacher and pupils had to deal with. The class had 21 pupils and 24 monitors, several of which were not functioning in all the lessons observed, which in this scenario was six out of seven lessons. One week before the RPis were used at all, I visited the school to help them set up some equipment and try out the RPis in the planned classroom. The design of the monitors was such that the adaptor cables needed to use the school monitors with the RPi would not fit, and so the school administration had to relocate a number of classes such that the RPi class could use the only classroom with sufficient and usable monitors. This was a relatively small room, and many of the activities in the Sonic Pi lesson plans involve ‘unplugged’ activities, which involve pupils moving around the room to simulate computational concepts. Several of these were abandoned by Teacher B after attempting the unplugged activities in the first two lessons.

Pupils worked in either pairs or threes on the activities, during lessons that lasted 50 minutes. The first lesson involved setting up the RPis, which took the majority of the lesson. As one group of female pupils were setting up, one of the study participants squealed at the prospect of disconnecting a cable from the tower PC they were using. This was indicative of a general reluctance, noticeable particularly with the girls, to handle the cables and connectors of the RPi and their classroom equipment. When asked about this, the group said they have always been told not to unplug equipment in case they break it. But by the final RPi lesson, the set up of equipment took a little under five minutes, and pupils were confidently unplugging and connecting monitors, boards, and other peripherals.

Teacher B had clearly developed a good relationship with the class observed, having no behavioural issues and the respect afforded him as a member of the senior leadership team was evident in the responses from the pupils as he arrived in the classroom and requested attention. He also knew the majority of the pupils very well, often referring to their extra curricular interests, and character driven anecdotes as part of his explanations. In particular, as a student musician himself, he connected his own experience with those musicians in the class and asked them to support others without a musical background in any composition related activities. Due to the space issues, he used very little of the unplugged activities and created some alternative exercises to help illustrate concepts, but these were predominantly done on screen. All lessons began with a recap of previous lessons and he also made regular connections to prior work on both Scratch and VB. One lesson was covered by a different member of staff, one of the two with a CS background, but the replacement had happened at the last minute and the teacher was given the lesson plan from the previous week instead of the next in the sequence, so this became more of a recap lesson – therefore in week 6, pupils recapped lesson 4.

Six pupils from the class participated in this study, two male and four female. Of the boys, 2C was very interested in Computing as a hobby and was emphatic about taking the subject as one of his options before the RPi lessons began. He was a quiet member of the class, always working with the same male partner and appeared to enjoy answering questions that the rest of the class struggled with. Teacher B occasionally singled him out to answer such questions, and thus this pupil seemed to have a strong sense of identification with and accountability to the subject and class. The other male, 2D, was also keen to take the subject but didn’t consider Computing to be a hobby other than using video games. He worked in a group with two other girls but this group worked in collaboration with groups either side of them, in supporting each other with both hardware and software work.

Of the four girls, 2B seemed to be considered by her peers as the ‘academic’ student, and was also one of the musicians to whom Teacher B sometimes referred. She worked in a group with another participant, 2F, who was quieter during the lessons but appeared to participate in the work on an equal footing. The other two girls, 2E and 2A worked in a group of three with another girl, who very much took on the role of leader in the group and was very vocal in discussion sessions. The classes were set in this year group, based on their Maths and English results, and this was one of two top set groups.

In this scenario, all sorts were paper based. The first sorts took place immediately before a lesson during break time in an available classroom, and the pupils were quite vocal in discussing and asking about the statements. They were asked about the statements at the extreme ends of the grid. The second sorts took place during lesson time but in a quiet room away from classes in two groups of three. As in the first scenario, pupils were given their first sorts back after completing the second and asked to find and comment on differences.

7.4. Scenario 3 – School C

School C had historically had very little support from the leadership team for ICT. A new Head began in 2010 but there was little change initially, and the subjects thought of as more traditionally academic, such as Latin, appeared to have far greater priority than ICT and Computing. Pupils therefore only did a half term of ICT during Y7 and Y8, and Teacher C had managed to increase the Y9 ICT lessons to one per week over the academic year. No qualifications were offered by the school in either IT or Computing at either KS4 or KS5.

Teacher C had a strong background in business, both in industry and education, and had taught ICT for several years at a challenging inner city school prior to working at school C. She was interested in Computing and was looking to groups such as CAS and the exam boards for additional training in this area. She used the national curriculum as a guide for the departmental scheme of work, but used the flexibility offered by her context to do activities focused more on enthusing the pupils towards the subject, with the aim of building demand for qualification options. As part of this, she decided to run a holiday club based on Computing that would be offered to all pupils.

The holiday club was just two full days of a two week holiday, pupils arriving at 9.30a.m. and leaving at 4.30p.m.. The teacher decided to use RPis as the school already had a considerable amount of equipment, such as Lego Mindstorms, and she wanted to use something different, but still aligned with Computing rather than ICT. She decided to offer a range of activities to give pupils some choice, and these consisted of using Minecraft Pi, using PiFace interface boards and Sonic Pi. All pupils were given demonstrations of these activities, and a ‘singing jelly baby’ activity that also used the PiFace board. On the first day, all pupils spent some time becoming familiar with the equipment and setting up, followed by the PiFace game activity. After this they were given free choice and all pupils chose the Minecraft activities. Eighteen pupils attended the summer school, ranging from Y7 to Y10, and all were male.

Most of the pupils had experience with Scratch and some had done some Python coding. The PiFace board activity required some additional set up, in creating the connection between the PiFace and the RPi to enable the software to communicate with Scratch. Once this was done, the pupils had two activities to work on. The first used the output and input capability of PiFace to enable control of an animated figure in Scratch. This allowed pupils to create a game such as a space invaders based game, where the buttons on the PiFace board controlled the movement and firing of the figure. The second activity taught some basic Python through creating a guessing game that incorporated the use of random numbers. The Minecraft activities involved coding with Python to automate actions in the game, so for example, pupils could create a small program to instantly build a building at a given location, to destroy an object or character, or to transport their avatar to any area of the world in which they were playing. Sonic Pi was described in the previous scenario.

The holiday club took place in Teacher C's usual classroom, which was a large room. There were 30 monitors arranged around the outside of the room and with an additional row created down the centre of the room, consisting of two rows of monitors back to back such that these pupils were facing each other. There were several spaces along the back of the classroom for doing work away from screen, and the desks were large enough for space to do written work with the keyboard put to one side. There was space at the front of the room for pupils to gather around the white board behind the teacher's desk, and the introduction to the activities and demonstrations took place here.

Despite the context of the holiday club, pupils generally remained engaged with the activities until mid afternoon on the second day. At this point all of the group were either playing internet games, or continuing to use Minecraft, but playing the full version rather than using the RPis. During the morning of the second day, a number of pupils had worked out how to network the RPis in order to play Minecraft collaboratively, although the nature of this collaboration was to use their Python code in attempts to destroy each other's creations without being caught.

Three pupils participated in the study from this scenario. Two, 3A and 3C were in Y9 and both were disappointed they were not able to take Computing as an option for qualifications. The third boy, 3B was in Y8 and all three considered Computing as a hobby, but only 3C did more than play computer games. He had instead tried some coding projects at home.

The first Q sorts in this scenario were used as a starter activity, ostensibly to get the pupils thinking about what Computing meant to them. All the pupils in the club attempted this. As there was plenty of space, this was again done as a paper based activity, but the nature of the context, being a holiday club rather than class time, meant that not all pupils completed it in the suggested way. The three pupils in the study, who did complete their sorts accurately, then performed a second sort during break time three weeks later. This additional time was given because Teacher C planned to do some RPi activities in an after school club during the week after the holiday period and additionally, some of the pupils, including these three boys, were able to borrow an RPi each to take home over the holiday period. As with the previous scenarios, the second Q sorts were compared to the former in a discussion following their completion.

7.5. Scenario 4 – School D

School D offered a range of qualifications in IT and CS at both KS4 and KS5. The Head of the department had a strong background in IT and Teacher D, who intended to use the RPis had a Masters degree in educational technology. At the time the study took place Teacher D was in his first year at this school. He intended to use the Sonic Pi resources because it fit well with the performing arts focus of the school, where many pupils had interests in music.

The Sonic Pi resources are described in scenario 2, but these had been refined since school B used them, two years before. The software had changed considerably, however Teacher D had bought the RPi equipment some time ago and decided to use the older version of the software, which was more limited but simpler, as this was preinstalled for the equipment he had and did not involve asking the school technicians to upgrade the operating system. Teacher D also added in an additional lesson for setting up the equipment and doing the Q sort with all pupils as a starter activity, and two final additional lessons, which were towards the end of term, for pupils to create their own compositions, in a similar way to School B.

The teacher had a mixed relationship with this class. He had decided to use the RPis with a Y8 class, and particularly during the last two weeks of the term, the pupils were less engaged with the activities. As a relatively new teacher to the school, he was still establishing relationships with the group, and there were a number of considerable but low-level behaviour issues that he had to deal with. There was a roughly equal split between the class of those who had some interest in the activity, whether that was from the Computing or music aspect, and those who had absolutely no interest in the subject. The group was a mixed ability class, with one pupil with severe special needs. They had one lesson of Computing per week across KS4 and had done work with Scratch and Code Academy, which provides resources to learn Python programming in a structured set of online resources.

Teacher D stuck mostly to the content of the lesson plans, completing all the unplugged activities although limiting the numbers of pupils involved with this. The space in the class was particularly limited, with a number of machines not working or peripherals missing, which led to several delays and frustration for the pupils. The mixed relationship with the class made the questioning aspect of the unplugged activities more difficult, but Teacher D still persisted with this and used these activities formatively.

Fifteen pupils from this learning scenario took part in the study, eleven female and four male. The low number of males taking part was due to a combination of first Q sorts not being completed in way that was usable (those that weren't had too much missing data in the sort) and to consent forms from parents not being returned. One pupil in this scenario had physical disabilities and had a teaching assistant with him at all times.

As described earlier, the Q sorts in this context were done online for pragmatic reasons. Screen shots of the online tool can be seen in Appendix E. The advantages of this were being able to use the Q sort as a whole class activity, such that the teacher could use them as formative data. The pupils also appeared to find it more manageable in a relatively short timeframe, as in other scenarios, pieces of paper with statements on were dropped, or blown out of place as the sorters were using them, which delayed the sorts. There is arguably accessibility advantages for pupils, for example in the case of the pupil with severe special needs, who was able to type his comments about the extreme placed statements, but would not have been able to hand write them. The biggest disadvantage was having less opportunity to talk to the pupils as they were completing their sorts, although they were still encouraged to ask about or discuss statements they were unsure of. The second sorts were also performed by the whole class and printed out, such that, in three small group interviews, pupils were able to do the comparison and reflection on the two sorts in the same way as the three other schools.

Chapter 8 – Q Analysis Results

"You never really understand a person until you consider things from his point of view ... until you climb into his skin and walk around in it" (Lee, To Kill a Mockingbird)

Introduction

In this chapter I present the findings from the Q analytical technique applied to two sets of sorts by 28 participants. Following Watts and Stenner (2012), I initially present the data representing shared viewpoints and explain the process that extracted these particular factors. I then interpret each factor in turn from a first person perspective to ensure that each 'voice' is fully represented. The process of interpretation is also guided by Watts (2014) who discusses the implications of conflating analysis and discussion, which "seems to encourage a descriptive, rather than a genuinely interpretative, engagement with the presented data" (2014, p.10). Each factor is given a description or label, simply to aid readability of the further analysis, with no inference that this label captures everything about the perspective given by that factor – the label only represents the full interpretation of the factor given in the first part of this analysis.

I have attempted in this analysis to incorporate the coverage of the methodology in addressing multiple levels of abstraction. Thus the statistical data such as variance is included for completeness, but this is with full recognition of the different emphasis of these numbers in Q such as, the total variance explained is not as relevant as the spread of variance across the factors, the latter which, if relatively evenly spread, reflects relatively significant factors and a justification for selecting that number of factors. As Brown explains, "the importance of a factor cannot be determined by statistical criteria alone, but must take into account the social and political setting to which the factor is organically connected " (1980, p.42, and 1978, pp.117-129).

The interpretation looks at statements at the extreme ends of the sort and moves inwards, which is where a -4 to +4 grid has limitations: the relative difference between those statements positioned in the neutral column and the end column does not allow the sorter to show as much range of feeling as a greater distribution would, but as I explained in chapter 6, the pilot study suggested this grid layout and associated number of statements was more manageable for this age group. In addition, the interpretation includes considering statements in their thematic and functional groupings: for example, the statement that CS is about building computers may be positioned negatively, but statements that CS is about software or problem solving may be even lower, in which case the pupil still considers the subject to be more about building computers than being about software or problem solving, even though that statement was placed in a negative column.

Once the factors or viewpoints have been presented on their own terms, I discuss differences and consensus of note across the factors within each study. I also look at these factors in relation to learning scenarios, in terms of whether a scenario is noticeably represented by a particular factor, and in concert with additional data on gender and parental interest in Computing. Once the story of each study has been told, I then go on to compare the Before and After studies at the collective level, in other words in terms of the shared factors: how the set of shared perspectives have changed, and how particular themes may have been privileged in different ways.

In the next stage, I include the individual level into the analysis, looking more at the emerging differences rather than consensus. In this stage, I look at the individuals working within each scenario, and consider for example those individuals who may have identified with a shared perspective in one study but not another, or those who don't share any perspective in either study. From this exploration I will consider what aspects of the RPi learning activities may have influenced the changes in pupils' understanding and construction of meaning around the Q sort, and the discussion chapter will then examine what these changes in perspective across levels and contexts tell us regarding developing knowledgeability and learning citizenship in RPi activities.

For each study, 'Before' and 'After' respectively, the data for the 28 participants was statistically analysed using the dedicated Q package PQMethod (Watts and Stenner, 2012). In both studies, four factors emerged from the analysis. A parallel analysis was run in both studies. For the Before study, the parallel analysis indicated the selection of just 2 factors, however the third and fourth factors were very close to being statistically acceptable and I considered them to be of interest due to a good number of participants loading on the additional factors (5 on factor 3 and on factor 4, 5 loading significantly plus 1 loading negatively making this a bi-polar factor, see further discussion below) and also due to the particular participants loading on that factor and the synergies with accompanying interview and observation data. In the After study, the parallel analysis indicated the extraction of three factors, however similar to the Before study, a fourth factor was of interest given the two pupils who loaded on that factor and the interesting perspective it presented.

8.1. Q Study 1 – 'Before'

The four factors emerging from the analysis explained 43% of the variance. 21 of the 28 participants loaded significantly on one of the four factors. The 4 factors were rotated using the orthogonal varimax procedure. A single factor exemplifying Q sort was then generated by weighted averaging of all the participant Q sorts that load significantly on that factor (see chapter 6). The full table of factor loadings is shown below (Table 8.1.) This table contains the loading of each participant on each factor and indicates significant loadings (indicated by an 'X'). A participant loading of 0.49 reached significance at $p<0.01$ in this study.

QSORT	Participants	F1	F2	F3	F4
1	2KFCM1 (2A)	-0.0242	0.2083	0.4037	**-0.5304X**
2	2KFMS1 (2B)	0.1363	0.4199	0.2471	0.2984

3	2KMCE1 (2C)	-0.2314	0.1325	**0.6926X**	0.1622
4	2KMJ1 (2D)	-0.1632	**0.5305X**	0.153	0.0288
5	2KFR1 (2E)	0.0241	**0.5405X**	0.0747	0.4667
6	2KFA1 (2F)	0.2654	0.2262	0.2086	**0.5553X**
7	1TMGC1 (1A)	0.0583	0.244	**0.6206X**	-0.2989
8	1TMJG1 (1B)	0.2344	0.2164	0.4681	0.3228
9	1TMSJ1 (1C)	0.4482	0.0777	0.3811	-0.1848
10	1TFV1 (1D)	-0.1408	-0.0754	-0.0471	**0.4900X**
11	3CMJS1 (3A)	**0.6438X**	-0.1961	0.0782	-0.2558
12	3CMAP1 (3B)	0.2476	0.1014	**0.5593X**	-0.3191
13	3CMJB (3C)	0.1744	-0.1701	**0.6596X**	-0.2658
14	4FFAB1 (4A)	0.1274	0.3653	**0.6055X**	-0.304
15	4FFDW1 (4B)	0.069	**0.6541X**	0.184	0.0643
16	4FFER (4C)	0.2793	**0.6176X**	0.1226	0.0365
17	4FMHO1 (4D)	0.2563	0.1896	0.0575	**0.4905X**
18	4FFJE1 (4E)	0.0541	0.2171	-0.2088	**0.6458X**
19	4FFLaG1 (4F)	-0.2176	0.1917	-0.1883	**0.5357X**
20	4FFLT1 (4G)	**0.6439X**	0.0421	0.1731	0.0716
21	4FFLG1 (4H)	**0.5100X**	0.3705	-0.0756	0.1913
22	4FFLW1 (4I)	**0.5382X**	0.2899	0.319	-0.0179
23	4FFMP1 (4J)	**0.5805X**	0.4842	0.2116	-0.1691
24	4FMRocH1 (4K)	0.0654	0.2781	-0.0106	0.0251
25	4FMRH1 (4L)	0.1982	-0.0536	0.3448	0.0423
26	4FMAW1 (4M)	-0.0737	0.0874	0.152	0.0625
27	4FFMW1 (4N)	0.3071	**0.6553X**	-0.1315	0.4707
28	4FFAE1 (4O)	0.4689	0.1777	-0.1819	0.0466

Table 8.1: Before study by factor loadings with an X Indicating a Defining Sort

8.1.1. Factor Bef1

Factor Bef1 – Connectors: Important but I'm not good at it

Factor Bef1 explains 10% of the study variance and has an eigenvalue of 5.1861. Five pupils load significantly on this factor. 3A is male and took part in scenario 3 (Minecraft Pi). His parents were working in the IT industry. The remaining four pupils were female and part of scenario 4 (the later Sonic Pi), 4G, 4H, 4I, and 4J, and only 4J had parents in the IT industry.

Computing for Connectors is a relevant subject, but not one in which learners are confident. They believe what they were going to learn about is important to their future (s17: +3), relevant to other subjects (s5: +2), and they are positive, though less certain, that what they learn from using the Raspberry Pi is something they will use again in the future (s8: +1). Although they see the relevance to other subjects, they don't believe that learning computing will help improve their marks in those subjects (s19: -2). They strongly believe they can improve how they learn in this subject (s16: +4). They are not confident at all that they could build a control device (s4: -3) or that they know more about computers than their peers (s13: -3). They are unsure whether others think they are good at working in a team (s14: 0) but confident that they are a good student (s24: +3).

Connectors believe anyone can learn to program (s29: +4) and that people can learn to program in their spare time without help from a teacher (s31: +2), but still think that CS is a really hard subject (s20: +2). They believe that CS is firstly about making software (s15: +1), then solving problems (s18: -1) and least of all about building computers (s12: -2). They are unsure whether they see CS as more like the natural sciences or social sciences (s26: 0). They are sure that being able to make and program computers is an enabler for making the world a better place (s9: +3), but do not see this as making those people more powerful (s3: -3). They aren't sure that they understand every day technology that they use, (s10: -1) but do think it is more important to be able to use computers in lots of ways than to control them (s27: +1). They believe that a program helping someone (s25: +1) is more important than it working correctly (s23: -2).

They are very sure that people who are into computers are not seen as geeky (s21: -4) and equally, don't believe that computer scientists need to be good at talking to people (s34: -4). For pupils with this perspective, they feel that what they learn is more important than the grades they get (s2: +2), and are neutral about tests and exams being the most important aspect of school (s11: 0). Their view of themselves as learners in this subject is that they do not learn more from listening to the teacher than from doing activities (s32: -2). Those with the factor Bef1 view are unsure as yet what they might do when they finish school (s22: -1).

8.1.2. Factor Bef2

Factor Bef2 – Dismissive of Computing: Not a relevant subject

Factor Bef2 explains 11% of the study variance and has an eigenvalue of 3.9241. Five pupils load significantly on this factor. Two of these pupils took part in scenario 2 (early Sonic Pi), one male, 2D and one female, 2E. The remaining three pupils were female and part of scenario 4 (Later Sonic Pi), 4B, 4C and 4N. 2D's parents worked in the IT industry.

Pupils who identify with this perspective, which I will refer to as Dismissives, see themselves as confident learners but Computing is not relevant to them. They have strong ideas about what they want to do when they leave school (s22: +4) and firmly believe they are a good student (s24: +4). What they learn is more important than what grades they get (s2: +3), however tests and exams are not unimportant (s11: 0). Learning how computers work is not relevant to their future (s17: -3), probably won't be used in the future (s8: -1) and it definitely won't help improve marks in other subjects (s19: -3), but there is some relevance between the learning activity with RPi and other subjects (s5: +1).

Programming ability doesn't at all make someone more powerful than those without it (s3: -4) or enable them to make the world a better place (s9: -3), and computer scientists definitely do not need to be good at talking to people (s34: -4). Being able to use computers in many ways is more important than the ability to program them (s27: +3).

They believe others think they are good at working in a team (s14: +2) and are quite sure that anyone can learn to program (s29: +2) though they are less certain whether this can be done in spare time without a teacher (s31: 0) or whether they learn more from the teacher talking than from doing activities (s32: 0). They can improve how they learn about Computing (s16: +3). They understand how the technology they use everyday works to some extent (s10: +1) and think friends may be interested in the RPi activities (s6: +1).

It is more important that a program works correctly (s23: +2) than that it helps someone (s25: +1). They aren't sure about what Computing really is, but it is more about building computers (s12: -1) than it is about making software (s15: -2) or solving problems (s18: -2)

8.1.3. Factor Bef3

Factor Bef3 – Geeks: Computing is key to my future

Factor Bef3 explains 11% of the study variance and has an eigenvalue of 1.7991. 5 pupils load significantly on this factor. Four of the pupils were male with one from scenario 1 (Pi in Space), 1A, one from scenario 2 (early Sonic Pi), 2C, and two from scenario 3 (Minecraft and PiFace), 3B and 3C. The remaining pupil, 4A, was female and part of scenario 4. 3B did not have parents working in the IT industry but all the other males did. 4A did not have parents working in the IT industry but had a grandfather who had been an electronic engineer and did electronics based activities with her.

The Geeks perspective is that Computing is a really important subject in which pupils are very interested. Pupils with this perspective are confident they know how to program a computer (s1: +4) and that this is something that can be learnt in one's spare time without a teacher (s31: +4). It isn't a difficult subject (s20: -4) and they could teach someone else how to program (s7: +3). What is learnt in Computing will be used in their future (s8: +3), and it is an important thing to learn (s17: +2). They believe they know more about computers than most people their age (s13: +1) and could build a control device (s4: +1). However, learning about it can't help improve marks in other subjects (s19: -3), and is not really relevant to other subjects (s5: -1). They don't strongly categorise Computing as natural science (s26: 0) but being a computer scientist definitely doesn't mean being good at talking to people (s34: -4).

CS is least about building computers (s12, -2) and more about making software (s15: 0) and solving problems (s18: 0). They can't improve how they learn about Computing and they believe they are good pupils (s24: +2). Anyone can definitely learn to program (s29: +3). Doing well in tests and exams is more important (s11: 0) than what they learn (s2: -1).

People who can program are probably more powerful than those who can't (s3: +1) and can probably make the world a better place (s9: +1). It is more important that a program works correctly (s23: +2) than that it helps someone (s25: +1) and it is more important to be able to program computers than to be able to use them in many different ways (s27: -2).

They are unsure about group work, whether pupils learn from each other (s30: 0), whether others learn from them (s28: -1) and think others would say they are not good at teamwork (s14: -2). They don't believe they learn through helping others (s33: -1), but they definitely do not learn more from teacher talk than from doing Computing activities (s32: -3).

8.1.4. Factor Bef4

Factor 4Before+ - Uncertain: Not sure about Computing but accountable to School

Factor Bef4 is a 'bi-polar' factor, which means that two opposed positions are expressed by the pupils who load on this factor, where the 'factor exemplifying' Q sort is the mirror image of the other. Brown (1980, p.134) suggests that bi-polar factors can demonstrate that, "the opposite of one idea may be another idea rather than a mere negation". However only 1 participant loads on this factor negatively, so rather than interpret the bi-polar factor here, this individual participant's sort will be considered within the section exploring the sorts on an individual level in the next chapter.

Factor Bef4 also explains 11% of the study variance and has an eigenvalue of 1.1795. 6 pupils load significantly on this factor (5 on Factor Bef4+ and 1 on Factor Bef4-). On the Bef4+ factor, 4 pupils were female and 1 male. One female took part in scenario 1 (Pi in Space), 1D, one in scenario 2 (early Sonic Pi), 2F, and two in scenario 4 (later Sonic Pi), 4E and 4F. The male, 4D, took part in scenario 4 and had a statement of special needs with moderate to severe cerebral palsy. The pupil, who loaded significantly on Factor Bef4-, 2A, was female, had parents who worked in IT and took part in scenario 2 (early Sonic Pi). Two of the females in scenario 4 had parents working in the IT industry. This factor will be referred to as Uncertains.

CS is a really hard subject from the Uncertains+ (s20: +4) perspective. They learn more from the teacher telling them things than from doing activities (s32: +4) but do also learn from working in a group (s30: +3) and helping others (s33: +2). They believe others perceive them as good at working in a team (s14: +2) and that they are a good student (s24: +2). Doing well in tests and exams is definitely the most important thing in school (s11: +3) and what is learnt is definitely not more important than this (s2: -2). People can't learn to program in their spare time without a teacher (s31: -3) and they aren't sure if anyone can learn to program (s29: 0).

They are not confident in Computing: they don't believe they know how to program (s1: -4), that they could build a control device (s4: -3), or that they know more about computers than most people their age (s13: -3). They don't believe they could teach someone else how to program (s7: -2). They think they might be able to improve how they learn about Computing (s16: +1). They aren't sure if learning Computing is relevant to their future (s17: 0) or will be used in the future (s8: -1), neither can they see much relevance to other subjects (s5: -1) or that it would improve marks in other subjects (s19: 0). They don't believe their friends would be impressed to hear about it (s6: -2).

CS is mostly about solving problems (s18: +1), and least about building computers (s12: -1). Being able to program is more important than the use of computers. CS is more like Maths and Physics than subjects like History and Sociology (s26: +2). Others see people who are into computers as geeky (s21: +1). Being able to program definitely doesn't mean one can make the world a better place (s9: -4) and those who can program are not more powerful than those who can't (s3: -1).

8.1.5. Before Study Discussion

Each of the factors above is a stand alone perspective, but I will now look across the factors in terms of the relationships between the perspectives, in particular the comparative positioning of: themes; statement groupings; and the individuals loading on each factor and groupings among participants.

8.1.5.1. Theme and statement relationships

In order to more easily explore the themes into which statements were categorised, each factor, or representative sort, is shown below in a sorted grid with themes colour coded.

	Efficacy/ legitimacy	Ways of knowing	Values/Learning citizenship	Connections
Self	Self-Efficacy	Self-Episteme	Self-LearningCitizen	Self-Connections
School	School-Efficacy	School-Episteme	School-LearningCitizen	School-Connections
Subject	Subject-Efficacy	Subject-Episteme	Subject-LearningCitizen	Subject-Connections

Figure 8.1: Theme matrix for Q analysis

Figure 8.2: Bef1 Connectors representative factor colour coded by theme

21. I think people who are into computers are seen as geeky	4. I think I could build a device that controls something	12. I think computer science is about building computers	10. I think I understand how the technology I use every day, like my mobile	1. I think I know how to program a computer	8. I think I will use in the future what we are learning	5. I think I can see how what we are learning will is relevant to other subjects I	17. I think learning about how computers work is really important for my	29. I think that anyone can learn to program
34. I think being a computer scientist means being good at talking to people	3. I think people who can program computers are more powerful than those who	19. I think I can improve marks I get in all subjects through learning about computing	7. I think I could teach somebody else how to program a computer	6. I think friends who haven't done this activity would/will be impressed to	25. I think if I write a program what is most important is that it helps somebody	2. I think what I learn is more important to me than the grades I get	9. I think people who make and program computers can make the world a	16. I think I can improve how I learn about computing
	13. I think I know more about computers than most people my age	23. I think if I write a program what is most important is that it works correctly	22. I think I have a good idea of what I want to do after I leave school	14. I think others think I am good at working in a team	15. I think computer science is about making software	20. I think computer science is a really hard subject	24. I think I am a good student	
		32. I think I learn more from the teacher telling me things than from doing the activity	18. I think computer science is about solving problems	26. I think computer science is like maths and physics more than it is like	27. I think being able to use computers in lots of ways is more important than	31. I think that people can learn to program in their spare time without a teacher		
			28. I think my friends or others in my group learn from me as much as I learn from	11. I think doing well in tests and exams is the most important thing in school	30. I think when we work in a group we learn from each other			
				33. I think I learn more when I am helping other people to do things				

Figure 8.3: Bef2 Dismissives representative factor colour coded by theme

3. I think people who can program computers are more powerful than those who	17. I think learning about how computers work is really important for my	15. I think computer science is about making software	20. I think computer science is a really hard subject	32. I think I learn more from the teacher telling me things than from doing the activity	5. I think I can see how what we are learning will is relevant to other subjects I	29. I think that anyone can learn to program	16. I think I can improve how I learn about computing	22. I think I have a good idea of what I want to do after I leave school
34. I think being a computer scientist means being good at talking to people	19. I think I can improve marks I get in all subjects through learning about computing	13. I think I know more about computers than most people my age	8. I think I will use in the future what we are learning	7. I think I could teach somebody else how to program a computer	6. I think friends who haven't done this activity would/will be impressed to	14. I think others think I am good at working in a team	27. I think being able to use computers in lots of ways is more important than	24. I think I am a good student
	9. I think people who make and program computers can make the world a	18. I think computer science is about solving problems	12. I think computer science is about building computers	11. I think doing well in tests and exams is the most important thing in school	10. I think I understand how the technology I use every day, like my mobile	23. I think if I write a program what is most important is that it works correctly	2. I think what I learn is more important to me than the grades I get	
		21. I think people who are into computers are seen as geeky	28. I think my friends or others in my group learn from me as much as I learn from	31. I think that people can learn to program in their spare time without a teacher	25. I think if I write a program what is most important is that it helps somebody	30. I think when we work in a group we learn from each other		
			1. I think I know how to program a computer	4. I think I could build a device that controls something	26. I think computer science is like maths and physics more than it is like			
				33. I think I learn more when I am helping other people to do things				

Figure 8.4: Bef3 Geeks representative factor colour coded by theme

Figure 8.5: Bef4 Uncertains representative factor colour coded by theme

Particular areas of note are the high positioning of efficacy/legitimacy at the level of self for Bef3 Geeks, and how these are generally low for all other three factors, with the exception of the one statement for factor Bef2 Dismissives, which relates to imagined trajectory (s22) and what they think they want to do after leaving school. For Bef4 Uncertains, efficacy/legitimacy in the subject is extremely low. Looking across the level of self, this is entirely towards the positive side of the grid for Bef3 Geeks, with the exception of ways of knowing statements. The ways of knowing theme is positioned lower for Bef3 Geeks compared to the other three also, and this theme is highest in Bef1 Connectors. This latter factor and Bef2 Dismissives both position the connections theme more strongly than the other two factors.

There were three consensus statements in this study, two of which are of interest predominantly in terms of their relation to other statements. These were statement 12, “I think computer science is about building computers” which was placed at -2 or -1 for all factors, but which is placed differently in relation to statements 15 (I think computer science is about making software) and 18 (I think computer science is about solving problems). Each factor took a different stance on the nature of the subject: Bef1 Connectors prioritised making software, Bef2 Dismissives building computers, Bef3 Geeks put making software and problem solving as equally most relevant, and Bef4 Uncertains had problem solving as the key element of Computing. The latter factor also associated Computing more highly with Maths and Physics than social science subjects.

Similarly statement 25 (I think if I write a program what is most important is that it helps somebody) was placed at position 1 for all factors, but is of interest mostly in relation to statement 23 (I think if I write a program what is most important is that it works correctly). Bef4 Uncertains placed these as equally important, suggesting that it wasn’t possible to have one without the other. Bef2 Dismissives and Bef3 Geeks place statement 23 as more important, suggesting that if a program doesn’t work correctly it isn’t possible for it to help anyone. Only Bef1 Connectors placed 25 as higher relative to 23, and the participant who loaded on two factors, (one of which was this Bef1 Connectors) suggested:

> “Well if it doesn’t help anyone then there’s not really much point is there?” [4J1]

All the factors except Bef4 Uncertains place the statement about relevance of Computing to other school subjects (s5) in a much more positive position than learning about Computing leading to improvement in other grades (s19). Within the theme matrix these statements relate to the connection theme at the level of school. The positioning of these suggests that the pupils within all three of these factors tend to separate the notions of learning from school assessment and see their experience of Computing as valuable to the generic learning process, but not as supporting their accountability to the regime of competence of being a school pupil. In contrast, Bef4 Uncertains place s5 and s19 in positions -1and 0 respectively. These are fairly neutral positions, but still highlight a connection between Computing with other subjects more in terms of its academic structure than the content. This is interesting in terms of the positioning relative to two other theme areas. Still within the connection theme but at the level of subject, the Bef4 Uncertains consider CS to be like maths and physics (s26) more than any other factor, suggesting that those who emphasise connections with those subjects more, also emphasise the academic structure of the subject, in how it can improve academic performance. Also interestingly in this regard, are the related statements regarding whether tests and exams are the most important aspect of school (s11) or whether learning is paramount (s2): Bef4 Uncertains is the only factor that places far more importance on exams (s11: +3, s2: -2).

All factors except Bef3 Geeks are positive about their ability to improve how they learn about Computing (s16), suggesting that from a Computing domain perspective they do not see learning as innate. Bef3 Geeks view could be conflating learning and academic performance again, in suggesting they can't improve their learning, but it could also indicate that they have a very high level of self-efficacy in this subject, or simply a deterministic view of learning in this domain. Supporting expressions of subject learning is the relative positioning of s29 (I think that anyone can learn to program) and s31 (I think people can learn to program in their spare time without a teacher) against s20 (I think computer science is a really hard subject). Whether people can learn to program on their own as a statement in isolation could be more related to self-directed learning than the nature of learning. But if positioned similarly to the notion that anyone can learn to program, which is more clearly a statement about learning in this domain, these statements are mutually supportive of representing the sorter's view on ways of coming to know in Computing: if they can learn without a teacher, it might be a reflection of a poor view of their teacher, but if they believe anyone can learn AND they can do it without a teacher, then this suggests programming competence is not considered innate or accessible only to an elite few.

For Bef3 Geeks, the subject is not hard at all, and this justifies their view that anyone can learn to program (s29: +3) in their spare time without teacher support (s31: +4). Bef1 Connectors perspective however is that CS is a really hard subject (s20: +2) and yet it is still possible for anyone to learn programming (s29: +4) and probably in their spare time without support (s31: +2). This positioning of the statements in this way could indicate an adaptive epistemic view of Computing, but could equally demonstrate a separation of the skill of programming with more conceptual understandings of CS.

For Bef1 Connectors, they strongly believe they can improve their learning in the subject, but this again could be because they are conflating learning with academic achievement, and the sorters actually mean they could get better grades in the subject. However, the fact that they place s29, anyone can learn to program, at +4, their belief that they can improve their own learning (s16) at +4, and people can do this without a teacher (s31) at +2 would indicate that there is an open minded view of learning this subject for Bef1 Connectors.

In this Before study, one of the participants had this to say about placing s31 at +4:

> "My friend has completed Code Academy and she hardly needed any help. People don't have to have a teacher to learn." [4I1]

Code Academy is focused on coding, but I believe this suggests that the online resources provided by this programme had given the pupil a stronger sense of efficacy in self-directed learning. Whether this affects underlying views of ways of knowing is uncertain. Ability to organise oneself to complete academic targets, does not necessarily equate to developing competence in a way that can be used in meaningful participation.

Bef1 Connectors and Bef2 Dismissives are the most positive about their learning abilities generally. In the case of Bef1 Connectors, this is also relative to the fact that they are the least confident about themselves as Computing pupils. These two perspectives also unite on the priority of programming, and therefore controlling computers, over simply being able to use them in many ways (Bef1 s27: +1; Bef2 s27: +3). In opposition, the perspectives of Bef3 Geeks and Bef4 Uncertains align in terms of placing this as less like how they think, (s27: -2 in both Bef3 and Bef4) positioning the statement that they have a good understanding of everyday technology as more like how they think (s10: 0 in both Bef3 and Bef4).

8.1.5.2. Participant groupings across factors

There was no factor that solely represented one scenario. The table below shows the spread of participants from scenarios across the factors.

	Bef1 Connectors	*Bef2 Dismissives*	*Bef3 Geeks*	*Bef4 Uncertains*	*No shared identification*
Sc1	0	0	1	1	2
Sc2	0	2	1	2	1
Sc3	1	0	2	0	0
Sc4	3	3	1	3	5

Table 8.2: Before study participant loadings across factors by scenario

Those whose parents or family were involved in the IT industry appeared to load predominantly on two factors, with 4 participants in this group loading significantly on Bef3, demonstrating that the Geek perspective at least is likely to have been influenced by parental perspective.

	Bef1 Connectors	*Bef2 Dismissives*	*Bef3 Geeks*	*Bef4 Uncertains*	*No shared identification*
N	3	4	1	3	4
Y	2	1	4	3	3

Table 8.3: Before study parental background in IT across factors

There was a more even spread of the girls across factors with boys loading predominantly on Bef3 or not loading on any factors.

	Bef1 Connectors	*Bef2 Dismissives*	*Bef3 Geeks*	*Bef4 Uncertains*	*No shared identification*
M	1	1	4	1	5
F	2	4	1	5	4

Table 8.4: Before study gender across factors

8.2. Q Study 2 – 'After'

The four factors emerging from the analysis explained 45% of the variance. 20 of the 28 participants loaded significantly on one of the four factors. The 4 factors were rotated using the orthogonal varimax procedure. A single factor exemplifying Q sort was then generated by weighted averaging of all the participant Q sorts that load significantly on that factor (see chapter 6). The full table of factor loadings is shown below (Table 2.) This table contains the loading of each participant on each factor and indicates significant loadings (indicated by an 'X'). A participant loading of 0.49 reached significance at p<0.01 in this study.

QSORT		1	2	3	4
	Participants				
1	2KFCM2 (2A)	**0.5921X**	0.3135	-0.1059	-0.0023
2	2KFMS2 (2B)	0.0369	0.3601	**0.6714X**	0.104
3	2KMCE2 (2C)	0.2887	0.4035	-0.2126	-0.1094
4	2KMJ2 (2D)	0.0856	-0.1406	**0.5317X**	0.2803

5	2KFR2 (2E)	-0.0745	-0.0934	**0.6770X**	0.174
6	2KFA2 (2F)	0.3706	0.0106	**0.6163X**	0.1157
7	1TMGC2 (1A)	0.0234	**0.6381X**	-0.1138	-0.1475
8	1TMJG2 (1B)	0.1804	**0.6722X**	-0.0002	0.0409
9	1TMSJ2 (1C)	-0.0004	**0.5244X**	0.1837	0.2666
10	1TFV2 (1D)	0.17	0.371	0.3404	-0.1399
11	3CMJS2 (3A)	0.4846	0.3073	-0.0998	0.3687
12	3CMAP2 (3B)	0.2123	**0.6515X**	0.0183	0.1869
13	3CMJB2 (3C)	0.0095	**0.7798X**	-0.0075	0.1084
14	4FFLG2 (4H)	0.2066	0.2611	0.4608	0.4569
15	4FFLW2 (4I)	**0.6355X**	0.1108	0.1074	0.3352
16	4FFMP2 (4J)	**0.5677X**	0.081	-0.0393	0.1026
17	4FMRH2 (4L)	0.1084	0.0055	**0.4871X**	-0.175
18	4FFAB2 (4A)	0.0907	**0.5907X**	0.0763	0.439
19	4FFDW2 (4B)	**0.8193X**	0.0021	0.069	0.0011
20	4FFER2 (4C)	**0.5608X**	0.2907	0.419	-0.0976
21	4FMHO2 (4D)	0.4573	0.0345	0.1401	0.2105
22	4FFJE2 (4E)	0.367	0.0205	0.4272	0.39
23	4FMRocH2 (4K)	0.1297	0.0581	-0.0631	**0.4888X**
24	4FFAE2 (4O)	0.1319	-0.1119	0.1882	**0.4854X**
25	4FFMW2 (4N)	**0.6204X**	-0.1167	0.386	0.2399
26	4FMAW2 (4M)	0.0555	-0.2912	-0.0576	0.0797
27	4FFLaG2 (4F)	0.3902	-0.2151	0.3096	-0.3069
28	4FFLT2 (4G)	-0.3469	0.044	**0.5475X**	-0.1017

Table 8.5: After study by factor loadings with an X Indicating a Defining Sort

8.2.1. Factor Aft1

Factor Aft1 – Dismissive of Computing: easy subject just not relevant

Factor Aft1 explains 13% of the study variance and has an eigenvalue of 5.6717. 6 pupils load significantly on this factor all six of whom are female. 2A took part in scenario 2 (early Sonic Pi) and the remaining five were part of scenario 4 (later Sonic Pi) 4B, 4C, 4I, 4J and 4N. The parents of 2A worked in IT, as did the parents of 4J.

Dismissives in the After study firmly believe that what is most important about writing a computer program is that it helps someone, (s25: +4) and that anyone can learn to program (s29: +4). They do think it is important that a program works correctly too, but less so than helping others (s23: +1). They really don't think that people who can program are more powerful than those who can't (s3: -4) and that learning about computers is important for their future (s17: -4). Similarly they don't believe they will use the learning from the RPi activity in their future (s8: -2) and they don't particularly believe people who can program can make the world a better place (s9: -1).

For Dismissives, Computing is not relevant to other subjects (s5: -2), and is perhaps more like a natural science than a social science (s26: +1). CS is most about making software (s15: +1), then building computers (s12: 0), and is least about solving problems (s18: -1). Being a computer scientist does not mean being good at talking to people (s34: -3).

Dismissives are quite confident they understand how the technology they use everyday works (s10: +2) and that being able to use it in lots of ways is more important than controlling it (s27: +1). They are not so confident they could build a control device, though more so than other factors (s4: 0).

Dismissives are confident that it is possible to learn programming in one's spare time (s31: +3). They believe people learn from each other when working in a group, but not that they learn more when helping others. They do feel that when working in a group, others learn as much from them as they do from others (s28: +2) and that their team working abilities are good in the eyes of others (s14: +1). This perspective is confident they can improve how they learn about Computing (s16: +2) but sure that they can't improve marks in other subjects through learning Computing (s19: -3). They aren't sure that they learn more from listening to the teacher than from doing activities (s32: -1). They don't think CS is a really hard subject (s20: -2).

8.2.2. Factor Aft2

Factor Aft2 – Geeks: Computing is key to my future and relevant to all

Factor Aft2 explains 13% of the study variance and has an eigenvalue of 2.9668. 6 pupils load significantly on this factor. One of these pupils, 4A is the female who did not have parents working in the IT industry but a grandfather who had been an electronic engineer and did electronics based activities with the girl, who took part in scenario 4 (later Sonic Pi). The remaining five pupils on this factor were male. Three, 1A, 1B and 1C took part in scenario 1 (Pi in Space) and of these, 1A and 1B, both had parents who worked in the IT industry. The two other pupils were from scenario 3, 3B and 3C and 3C had parents working in the IT industry.

Geeks have a demonstrable confidence and interest in the subject. They believe they know more about computers than most people their age (s13: +4), that learning how computers work is really important for their future (s17: +4) and that they will use what they are learning in the future (s8: +3). They don't at all think CS is a hard subject (s20: -4), and are confident they know how to program (s1: +3), but they are not sure they could teach someone else how to program (s7: 0). They also are not confident they understand how technology they use every day works (s10: -1). More than other perspectives they believe that those who can program are more powerful than those who can't (s3: +2) and they also believe programmers can make the world a better place (s9: +2).

Their view of CS is that it is mostly about solving problems (s18: 0), then making software (s15: -1) and least about building computers (s12: -2). They see the subject as more of a natural than social science (s26: +1). They can see some relevance in what they have learnt to other subjects (s5: +1) but not that marks can be improved in other subjects through learning Computing (s19: -3). It isn't more important to be able to use computers in lots of ways than to be able to program them (s27: -2).

Geeks do not place a lot of importance on the teacher – they do not believe they learn more from listening to the teacher than from doing activities (s32: -4), and they believe one can learn to program in their spare time (s31: +2). They don't think others see them as good team workers (s14: -2). They may learn more when they help others (s33: +1), and may learn from each other during group work (s30: +1), but don't think others in a group learn as much from them as they do from others (s28: -1). They aren't sure that they could improve how they learn about Computing (s16: 0) and are positive, but not particularly confident, that anyone can learn how to program (s29: +1).

Geeks are least sure of all perspectives about what they want to do when they leave school (s22: 0). What they learn is slightly less important than doing well in tests and exams (s2: -2; s11: -1). They believe it is more important that a program works correctly than that it helps someone (s23: +2; s25: 0).

8.2.3. Factor Aft3

Factor Aft3 – Unconfident: Aligned with School practice but can't do Computing

Factor Aft3 explains 12% of the study variance and has an eigenvalue of 2.3480. Six pupils load significantly on this factor. Two were male, one of whom took part in scenario 2 (early Sonic Pi), 2D. He was the only pupil on this factor whose parents did work in the IT industry. The other male took part in scenario 4 (later Sonic Pi), 4L. The remaining four pupils were female: three from scenario 2 also, 2B, 2E and 2F; and one from scenario 4, 4G.

For the Unconfident perspective the most important thing about school is doing well in tests and exams (s11: +4). For these pupils, it is not the case that what is learnt is also important as this is placed relatively negatively (s2: -1). Pupils loading on this factor strongly believe they are good pupils (s24: +4). These pupils have a good idea of what they want to do when they leave school (s22: +3).

These pupils are very sure that their friends would not be impressed to hear about the RPi work they have done (s6: -4). There is some relevance of the RPi activity to other subjects (s5: +1) and it might be important to learn about for their future (s17: +1) but they aren't sure how they will use it in future (s8: -1).

They have little confidence in their ability to build a control device (s4: -4), knowing how to program (s1: -2) or to teach others how to program (s7: -2), and they see CS as a hard subject (s20: +2). Whether anyone can learn to program is uncertain (s29: 0) and they probably couldn't learn to program in their spare time (s31: -1). These pupils see teacher talk and doing activities as equal, or dependent on other considerations (s32: 0).

These pupils are generally ambivalent about group work but confident that others think of them as good team workers (s14: +3). They don't think others in a group learn as much from them as they learn from others (s28: -1), they aren't sure that group members learn from each other (s30: 0) or particularly that they learn when helping others (s33: 0). They are sure they do not know more about computers than most people their age (s13: -3) and they can't improve marks in other subjects through learning Computing (s19: -3) but they could improve how they learn about Computing (s16: 2).

CS is mostly about solving problems (s18: 1), then making software (s15: 0) and least about building computers (s12: -2). The subject is definitely more like Maths and Physics than History and Sociology (s26: +2). Computer Scientists definitely don't need to be good at talking to people (s34: -3). It is more important to be able to use computers in lots of ways than to be able to program them (s27: +2) and it is more important that a program works correctly (s23: +3) than that it helps someone (s25: +1).

8.2.4. Factor Aft4

Factor Aft4 – Learners: Unconfident and uncertain in Computing but here to learn

Factor Aft4 explains 7% of the study variance and has an eigenvalue of 1.3415. 2 pupils load significantly on this factor, both from scenario 4 (later Sonic Pi), one male, 4K, whose parents did not work in IT and one female, 4O, whose parents did.

For this factor, learning with others is a priority. They believe group work enables pupils to learn from each other (s30: +4) and that they learn more when helping others (s33: +4). They are still positive but not as sure whether others see them as good at working in a team (s14: +1), and whether their peers learn as much from them as they do from their peers (s28: +1). They strongly prioritise learning as the important aspect of school (s2: +3) as opposed to doing well in tests and exams (s11: -3). They don't however think they can improve how they learn about Computing (s16: -1) and they are least sure of all factors that they are a good student (s24: 0). They do think that they can improve the marks they get in other subjects through learning about Computing (s19: +1) but don't see the relevance of the RPi activity to other subjects (s5: -2).

CS is mostly about making software (s15: +2), then building computers (s12: 0) and is least about problem solving (s18: -1). It is more like Maths and Physics than social sciences (s26: +2). Being a Computer Scientist doesn't necessarily mean being good at talking to others (s34: 0). Being able to use computers in lots of ways is definitely more important than being able to program them (s27: +3), but this perspective doesn't think they understand how the technology they use everyday works (s10: -3).

People who are into computers are not seen as geeky (s21: -4) and those with this perspective believe their friends would be impressed to hear about the RPi activity (s6: +2). But these pupils are not confident in their Computing abilities. They do not believe they could teach someone else how to program (s7: -4), and they don't think they know how to program a Computer (s1: -2). They believe those who can program can make the world a better place (s9: +3) but this doesn't make them more powerful (s3: -3). It is more important that a program works correctly (s23: +1) than that it helps someone (s25: -2). They aren't sure if anyone can learn to program (s29: 0).

8.2.5. After Study Discussion

As with the Before study, I will now look across the factors in terms of the relationships between the perspectives.

8.2.5.1. Theme and statement relationships

	Efficacy/ legitimacy	Ways of knowing	Values/Learning citizenship	Connections
Self	Self-Efficacy	Self-Episteme	Self-LearningCitizen	Self-Connections
School	School-Efficacy	School-Episteme	School-LearningCitizen	School-Connections
Subject	Subject-Efficacy	Subject-Episteme	Subject-LearningCitizen	Subject-Connections

Figure 8.6: Theme matrix for Q analysis (repeat of Fig.8.1)

Figure 8.7. Aft1 Dismissives representative factor colour coded by theme

3. I think people who can program computers are more powerful than those who	19. I think I can improve marks I get in all subjects through learning about computing	11. I think doing well in tests and exams is the most important thing in school	7. I think I could teach somebody else how to program a computer	1. I think I know how to program a computer	15. I think computer science is about making software	10. I think I understand how the technology I use every day, like my mobile	24. I think I am a good student	25. I think if I write a program what is most important is that it helps somebody
17. I think learning about how computers work is really important for my	21. I think people who are into computers are seen as geeky	5. I think I can see how what we are learning will is relevant to other subjects I	9. I think people who make and program computers can make the world a	13. I think I know more about computers than most people my age	26. I think computer science is like maths and physics more than it is like	16. I think I can improve how I learn about computing	30. I think when we work in a group we learn from each other	29. I think that anyone can learn to program
	34. I think being a computer scientist means being good at talking to people	20. I think computer science is a really hard subject	32. I think I learn more from the teacher telling me things than from doing the activity	4. I think I could build a device that controls something	14. I think others think I am good at working in a team	22. I think I have a good idea of what I want to do after I leave school	31. I think that people can learn to program in their spare time without a teacher	
		8. I think I will use in the future what we are learning	18. I think computer science is about solving problems	12. I think computer science is about building computers	27. I think being able to use computers in lots of ways is more important than	28. I think my friends or others in my group learn from me as much as I learn from		
			33. I think I learn more when I am helping other people to do things	6. I think friends who haven't done this activity would/will be impressed to	23. I think if I write a program what is most important is that it works correctly			
				2. I think what I learn is more important to me than the grades I get				

Figure 8.8: Aft2 Geeks representative factor colour coded by theme

Figure 8.9: Aft3 Unconfidents representative factor colour coded by theme

Figure 8.10: Aft4 Learners representative factor colour coded by theme

7. I think I could teach somebody else how to program a computer	3. I think people who can program computers are more powerful than those who	1. I think I know how to program a computer	4. I think I could build a device that controls something	29. I think that anyone can learn to program	14. I think others think I am good at working in a team	6. I think friends who haven't done this activity would/will be impressed to	2. I think what I learn is more important to me than the grades I get	33. I think I learn more when I am helping other people to do things
21. I think people who are into computers are seen as geeky	10. I think I understand how the technology I use every day, like my mobile	5. I think I can see how what we are learning will is relevant to other subjects I	8. I think I will use in the future what we are learning	20. I think computer science is a really hard subject	19. I think I can improve marks I get in all subjects through learning about computing	26. I think computer science is like maths and physics more than it is like	27. I think being able to use computers in lots of ways is more important than	30. I think when we work in a group we learn from each other
	11. I think doing well in tests and exams is the most important thing in school	17. I think learning about how computers work is really important for my	16. I think I can improve how I learn about computing	24. I think I am a good student	23. I think if I write a program what is most important is that it works correctly	15. I think computer science is about making software	9. I think people who make and program computers can make the world a	
		25. I think if I write a program what is most important is that it helps somebody	18. I think computer science is about solving problems	13. I think I know more about computers than most people my age	28. I think my friends or others in my group learn from me as much as I learn from	22. I think I have a good idea of what I want to do after I leave school		
			32. I think I learn more from the teacher telling me things than from doing the activity	12. I think computer science is about building computers	31. I think that people can learn to program in their spare time without a teacher			
				34. I think being a computer scientist means being good at talking to people				

The theme patterns that are highlighted by these representative sorts include particularly low efficacy/legitimacy in the subject for Aft3 Unconfidents and Aft4 Leaners. Aft3 Unconfidents position efficacy/legitimacy statements as low for this perspective, with the exception of a positive imagined trajectory. There is an emphasis on the school level in Aft4 Learners. Aft2 Geeks have relatively higher efficacy/legitimacy and the level of self predominates the positive end of the grid.

There are two views on the most important aspect of Computing in this study. Aft2 Geeks and Aft3 Unconfidents agree that problem solving is the most important aspect and building computers the least, whereas Aft1 Dismissives and Aft4 Learners believe making software is the most important and problem solving is the least. The latter two factors have all but one significantly loading participant from scenario 4. This could simply reflect the Sonic Pi activity, but the majority of scenario 2, who also did Sonic Pi, load on Aft3 Unconfidents. These two factors, Aft 1 Dismissives and Aft4 Learners, also see learning as more important than exams, though Aft1 Dismissives and Aft2 Geeks put these two statements relatively close together, whereas Aft3 Unconfidents position exams as much more important, and Aft4 Learners place learning as much more important. Aft3 Unconfidents are the most certain about what they want to do when they leave school and Aft2 Geeks are the least certain.

Aft3 Unconfidents appear to believe that CS is a hard subject more than all other factors. Aft2 Geeks believe it is not hard at all. Aft3 Unconfidents and Aft4 Learners believe Computing is more like a natural science than Aft1 Dismissives and Aft2 Geeks. All the first three factors say being a computer scientist does not mean being good at talking to people but Aft4 Learners are neutral about this. Aft3 Unconfidents mostly think that those into computers are seen as geeks, but still position this negatively relative to other statements. Aft4 Learners most disagree that this is the case.

Only Aft1 Dismissives put the importance of helping others with a program above it working correctly. Particularly Aft3 Unconfidents believe getting a program working correctly is more important, but working correctly is relatively positive in all cases and helping others is only placed in a negative position in Aft4 Learners. Aft1 Dismissives are also most negative about those who can program being more powerful than those who can’t and being able to make the world a better place. Aft4 Learners also suggest they aren’t more powerful but do believe they can make the world a better place. Aft3 Unconfidents are neutral on both of these issues but Aft2 Geeks are very positive about both.

Aft2 Geeks and Aft3 Unconfidents don’t think friends learn as much from them as much as they learn from friends, but Aft3 Unconfidents are confident that others think they are good at teamwork nonetheless, whereas Aft2 Geeks do not. Aft1 Dismissives think that others learn from them and also that they are seen as good team workers and so appear the most confident in their academic position. Aft3 Unconfidents are the least negative about learning from the teacher rather than doing activities. Aft4 Learners are most positive about learning from helping others and learning in a group whereas Aft1 Dismissives are the most negative about learning from helping others.

With the exception of Aft4 Learners who are unsure, all are positive about seeing themselves as a good student, especially Aft3 Unconfidents. Aft2 Geeks are the most confident in the subject of Computing – they know more than most, believe they can teach others how to program, and believe they know how to program. They are however, less sure than Aft1 Dismissives that they could build a control device. Aft3 Unconfidents are the least confident within the subject, and Aft4 Learners also appear to lack confidence. The latter think friends would be impressed to hear about the RPi activities, but Aft3 Unconfidents don't. Aft3 Unconfidents thus appear unsure about the usefulness of the subject for them, whereas Aft4 Learners do see it as relevant and useful, but do not think of themselves as good at the subject.

Aft1 Dismissives and Aft3 Unconfidents place the ability to improve their learning of Computing at the highest placing for this statement, Aft4 Learners are the only perspective negative on this, but are positive on the ability to improve marks in other subjects through learning Computing, whereas all the others are negative at -3. Aft4 Learners and Aft 3 Unconfidents are neutral regarding whether anyone can learn to program. Aft1 Dismissives are confident this is the case, and Aft2 Geeks are slightly less positive. Aft1 Dismissives are confident it is possible to learn programming in one's spare time but Aft3 Unconfidents are not. Aft2 Geeks and Aft4 Learners are also positive on this though less so than Aft1 Dismissives.

Aft1 Dismissives do not see Computing as an important subject, not something they are going to use in the future and not relevant to other subjects, suggesting little or weak connections within and across the subject and their wider curriculum. Aft2 Geeks are the opposite in this regard, seeing Computing as important, relevant and something they will use in the future. Aft4 Learners again do not see the subject as relevant to others, but do think learning about it can improve marks, which as in the Before study, suggests the separation of learning competencies and academic skills. Also as in the Before study, Aft4 Learners positively place Computing as being like Maths and Physics. Aft3 Unconfidents think the subject is relevant to other subjects but not that they could improve marks in these, as do Aft2 Geeks. Aft2 Geeks are the only factor that doesn't prioritise the importance of using computers in many ways over programming them. Only Aft1 Dismissives think they understand how technology they use everyday works.

8.2.5.2. Participant groupings across factors

The four factors in the After study more noticeably converge around the different learning scenarios. In itself, this suggests there has been an influence on shared perspectives by the learning design of each scenario, and the comparative section below will explore how these changes have manifested in the new perspectives. Five out of the six participants loading significantly onto Aft1 Dismissives are from scenario 4 (later Sonic Pi), and both participants in Aft4 Learners are also from scenario 4. Four out of the six participants on Aft3 Unconfidents are from scenario 2 (early Sonic Pi). Aft2 Geeks is split with: three participants from scenario 1, (Pi in Space) where only one from this scenario is missing, the latter whom did not load onto any factor; two participants from scenario 3, (Minecraft and PiFace), with the other participant from scenario 3 not loading significantly onto any factor, though very close to loading on Aft1 Dismissives; and one participant from scenario 4.

	Aft1 Dismissives	*Aft2 Geeks*	*Aft3 Unconfidents*	*Aft4 Learners*	*No shared identification*
Sc1	0	3	0	0	1
Sc2	1	0	4	0	1
Sc3	0	2	0	0	1
Sc4	5	1	2	2	5

Table 8.6: After study participant loadings across factors by scenario

Regarding parental perspective, there is more clearly a loading on Aft2 Geeks or non significant. With regard to gender, the largest grouping is associated with Aft1 Dismissives, followed by Aft2 Geeks.

	Aft1 Dismissives	*Aft2 Geeks*	*Aft3 Unconfidents*	*Aft4 Learners*	*No shared identification*
N	4	2	5	1	3
Y	2	4	1	1	5

Table 8.7: After study parental background in IT across factors

	Aft1 Dismissives	*Aft2 Geeks*	*Aft3 Unconfidents*	*Aft4 Learners*	*No shared identification*
M	0	5	2	1	4
F	6	1	3	1	5

Table 8.8: After study gender across factors

Chapter 9 - Study comparison

“He had two selves within him apparently, and they must learn to accommodate each other and bear reciprocal impediments. Strange, that some of us, with quick alternate vision, see beyond our infatuations, and even while we rave on the heights, behold the wide plain where our persistent self pauses and awaits us.” (Eliot, Middlemarch)

“Mutability is the epitaph of worlds. Change alone is changeless.” (Isabella Banks, Manchester Man)

Introduction

In this chapter I will take the data from the two Q studies in the previous chapter, and explore the differences between them at individual and collective levels. I will compare the overall studies and each scenario in turn.

9.1. Factor mappings across Before and After

In order to see more clearly the way in which pupils from each scenario have loaded on factors in each study, the two tables are placed side by side below. There is more of a spread across the factors in the Before study than in the After study, in the latter which we can more clearly associate scenario 4 (later Sonic Pi) mostly with Aft1 Dismissives or not sharing a perspective, scenario 1 (Pi in Space) mostly with Aft2 Geeks, and scenario 2 (early Sonic Pi) with Aft3 Unconfidents.

	Bef1 Connectors	*Bef2 Dismissives*	*Bef3 Geeks*	*Bef4 Uncertains*	*No shared identification*
Sc1	0	0	1	1	2
Sc2	0	2	1	2	1
Sc3	1	0	2	0	0
Sc4	4	3	1	3	4

	Aft1 Dismissives	*Aft2 Geeks*	*Aft3 Unconfidents*	*Aft4 Learners*	*No shared identification*
Sc1	0	3	0	0	1
Sc2	1	0	4	0	1
Sc3	0	2	0	0	1
Sc4	5	1	2	2	5

Table 9.1: Before and After study participant loadings on factors by scenario

The factors do not map directly to the same number in the alternative study in terms of participants and similarities. The table below demonstrates the participants positioned within each factor for both studies, and looking at these connections it appears that the Bef3 Geeks factor most clearly map to Aft2 Geeks (hence the decision to use an equivalent label). All but one of those loading on this factor in the Before study, also loaded on Aft2 Geeks in the After study. One pupil, 2C, no longer loaded on any factors in the After study, and two of the remaining three participants from scenario 1 (Pi in Space), 1B and 1C, now also load on the Geeks factor, having not loaded on any in the Before study.

	Aft1 Dismissives	*Aft2 Geeks*	*Aft3 Unconfidents*	*Aft4 Learners*	*Aft NS*
Bef1 Connectors	4I, 4J		4G		3A, 4H
Bef2 Dismissives	4B, 4C, 4N		2D, 2E		
Bef3 Geeks		1A, 3B, 3C, 4A			2C
Bef4 Uncertains	2A		2F		1D, 4D, 4E, 4F
Bef NS		1B, 1C	2B, 4L	4K, 4O	4M

Table 9.2: Before and After study participant loadings on factors by individual

Factor Bef2 Dismissives map to Aft1 Dismissives for three pupils in scenario 4 (later Sonic Pi), with two additional pupils from that scenario, 4I and 4J joining the factor. The other two pupils in the Bef2 Dismissives, both from scenario 2 (early Sonic Pi), now map to Aft3 Unconfidents, where they are joined by two others from that scenario, one of whom, 2F, was previously loading on Bef4 Uncertains, and the other, 2B, who in the Before study did not load on a shared viewpoint. The Dismissives label was given to Bef2 and Aft1 as these are the most similar, but the differences between these, and the differences with the alternative mapping to Aft3 Unconfidents, is also of interest as will be discussed below.

The participants identifying with Bef1 Connectors in the Before study have moved in a mixed way. 3A from scenario 3 (Minecraft and PiFace) does not identify with any factor in the After study, and neither does 4H from scenario 4 (later Sonic Pi). 4G now identifies with Aft3 Unconfidents and 4I and 4J now identify with Aft1 Dismissives.

Four of the participants loading on factor four in the Before study now do not identify with any shared perspectives: three pupils from scenario 4 (later Sonic Pi) and one from scenario 1 (Pi in Space). Both the pupils from scenario two who shared this view in the Before study now load on a factor but respectively different ones: pupil 2A has moved from Bef4 Uncertains to Aft1 Dismissives; and 2F has moved to Aft3 Unconfidents.

9.2. Factor theme and statement positioning comparison

9.2.1. Points of consensus

There was consensus in the before study around the statement that CS is about building computers. Looking at the factors that map most directly, this did not change position for the Geeks, who continued to place this relatively low, but the Dismissives place it higher. Aft3 Unconfidents continued to position it as less important, but Aft4 Learners had this as a neutral statement. These changes suggest the hardware focus of using the RPi may have emphasised the building element. There was consensus in the After study that CS is more like natural than social sciences, whereas in the Before study, two of the factors were neutral about this, suggesting that the RPi learning designs may have emphasised connections with maths and science.

In the Before study, there was consensus on the most important target in writing a program is that it helps someone, whereas in the After study, there was consensus on the importance of the program working correctly. Of course, these two statements are related so what is pertinent, is that in the Before study, two factors had working correctly as prioritised, one factor had them equally weighted, and the other had helping people prioritised. In the After study, three factors had working correctly as prioritised and only one Factor, Aft1 Dismissives, had helping someone as a priority.

9.2.2. Mapped factor changes – Geeks before and after

Looking at themes, the Geeks factors are still similar but the emphasis on self has noticeably shifted (the tables for these factors are shown again here).

	Efficacy/ legitimacy	Ways of knowing	Values/Learning Citizen	Connections
Self	Self-Efficacy	Self-Episteme	Self-LearningCitizen	Self-Connections
School	School-Efficacy	School-Episteme	School-LearningCitizen	School-Connections
Subject	Subject-Efficacy	Subject-Episteme	Subject-LearningCitizen	Subject-Connections

Figure 9.1: Theme matrix for Q analysis (repeat of Fig.8.1)

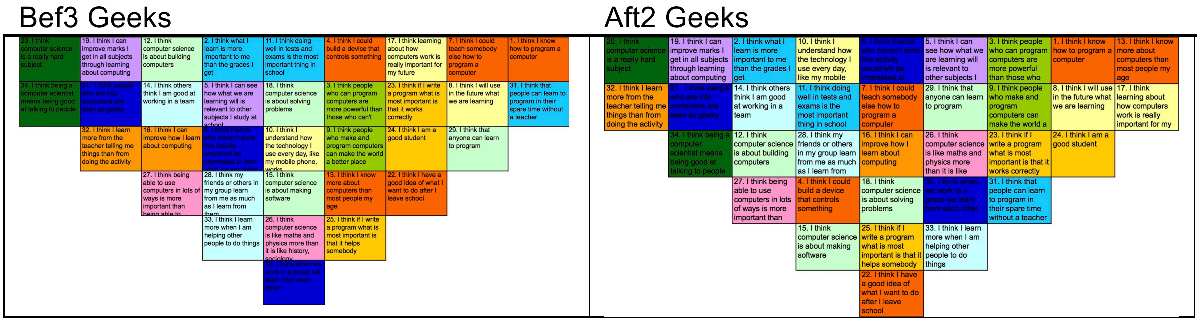

Figure 9.2: Before and After study Geek representative factors colour coded by theme

The Geeks are less confident about their Computing ability, for example, the statement about their ability to build a control device has moved from a positive to a negative position (s4: from +1 to -1) and whether they feel they know how to program and whether they could teach someone else (s7: from +3 to 0) have both become less positive. They are now much more positive that relative to their peers, they know more about computers (s13: from +1 to +4). The ordering of statements about ways of knowing for Computing now positions solving problems as the main focus, whereas in the Before study, this was equal to software development. They see more relevance to other subjects (s5: from -1 to +1) and they believe more strongly that learning Computing is relevant to their future (s17: from +2 to +4).

They are also more sure about the possibility of improving their learning (s16: from -2 to 0), and at the same time, less sure that anyone can learn to program (s29: from +3 to +1) or that people can learn to program without a teacher (s31: from +4 to +2). Whether programming ability gives people more power (s3) and can help make the world a better place (s9) have both become slightly more privileged for the Geeks, moving from +1 to +2. Learning through helping others (s33) has moved from a negative -1 to positive +1 position.

9.2.3. Mapped factor changes – Dismissives and Unconfidents

As discussed in the previous section, pupils from Bef2 Dismissives that took part in scenario 4 (later Sonic Pi) mapped to a similar factor, Aft1 Dismissives. Those from scenario 2 (early Sonic Pi) mapped to Aft3 Unconfidents. I will consider the two Dismissives factors first.

Dismissives still position what they learn as being more important than test and exam results, but both of these have moved to more negative positions (s2: from +3 to 0; s11: from 0 to -2). Like the Geeks, they now see less relevance to other subjects (s5: from +1 to -2). They have changed their view on what matters most for programming, in the Before study placing it working correctly at +2 and helping someone at +1, and in the After study placing these respectively at +1 and +4.

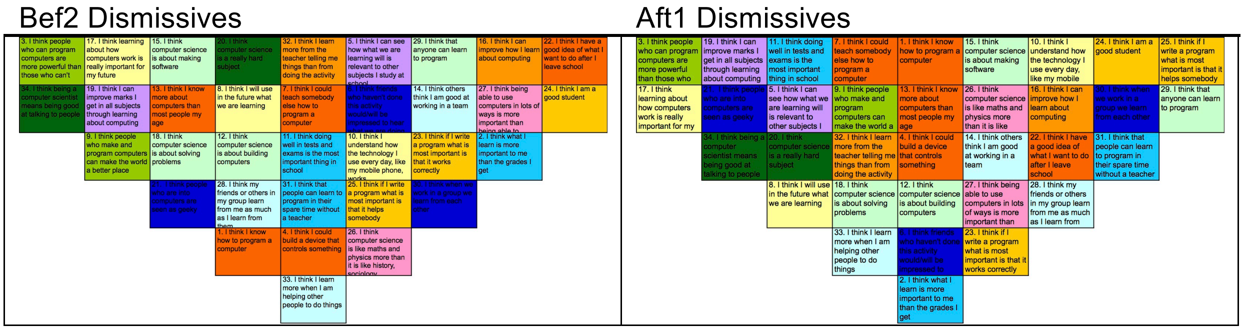

Figure 9.3: Before and After study Dismissives representative factors colour coded by theme

They are less sure about what they want to do when they leave school (s22: from +4 to +2) and aren't as sure that being able to use computers in lots of ways is more important than controlling them (s27: from +3 to +1). In contrast to the Geeks, they now feel that anyone can learn to program in their spare time without teacher support (s31: from 0 to +3) and that anyone can learn to program (s29: from +2 to +4).

Previously, this factor believed CS was mostly about building computers and least about software and problem solving, the latter two being in equal position. In the After study, they position software more highly (s15: from -2 to +1), and solving problems as least relevant (s18: from -2 to -1). They are now more positive than in the Before study about whether people with Computing skills can make the world a better place (s9: from -3 to -1). They are more confident they know more than most their age (s13: from -2 to 0) and are much more confident about others learning from them during team work (s28: from -1 to +2).

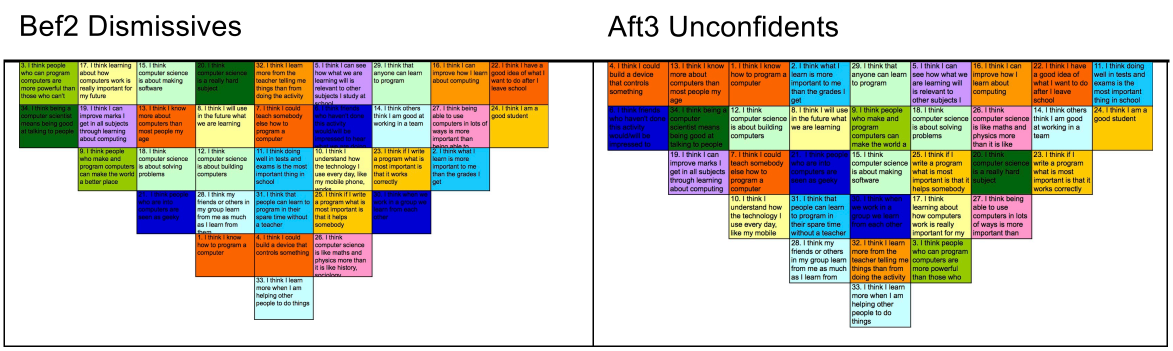

Figure 9.4: Bef2 Dismissives and Aft3 Unconfidents representative factors colour coded by theme

Scenario 2 (early Sonic Pi) pupils who moved from Dismissives to Unconfidents, have most noticeably changed in how much power they believe people who can program have (s3: from -4 to +1). They also are more positive about these abilities enabling making the world a better place (s9: from -3 to 0). Their views on learning and exams are markedly different, in Bef2 Dismissives placing tests and exams as less important to them than their learning, and in the After study both of these have swapped and become more polarised (s2 (learning): from +3 to -1; and s11 (exams): from 0 to +4).

The views on subject ways of knowing have changed from being about building computers mostly, with software and problem solving placed equally, to positioning problem solving first, and they have become more spread (s18: from -2 to +1), then software (s15: from -2 to 0), and least of all building (s12: from -1 to -2).

Aft3 Unconfidents are much more sure that learning about Computing is important for their future (s17: from -3 to +1) and also now think CS is a really hard subject (s20: from -1 to +2). But having done their RPi activity, they really don't think their friends would be interested to hear about it (s6: from +1 to -4). They are also less confident in their Computing ability, in terms of being able to teach someone else how to program (s7: from 0 to -2) and being able to build a control device (s4: from 0 to -4). They are now less sure that they know how technology they use every day works (s10: from 1 to -2) and that anyone can learn to program (s29: from +2 to 0).

9.3. Scenarios

9.3.1. Scenario 1 – Pi in Space

Pupil	Before Factor	After Factor
1D	Uncertains	NS
1A	Geeks	Geeks
1B	NS	Geeks
1C	NS	Geeks

Table 9.3: Scenario 1 participants factor loading

The table above shows the movement across factors for the pupils in this scenario. This would suggest pupil 1D had a different experience of the learning activity than the other three. Observations certainly support this: 1D was the only female pupil who remained with the project until the end and had joined the group with more of an interest in electronics than Computing. The three boys had worked together on the coding tasks and had sat separately to 1D and the other club attendee at almost every session. 1D took on the research into components needed to put a unit with a webcam and RPi together, and to launch it. One session took place in the Design and Technology lab, with a STEM ambassador from the neighbouring university, and this session involved soldering components onto breadboards. This was the only session in which 1D and the three boys worked collaboratively as she demonstrated some electronics and helped the younger of the three boys with the soldering.

In the interview following her second Q sort, she described how they took on different roles in the project:

> 1D: We all did different parts

I: And your part was ..?

1D: Kind of like the engineer that kind of built the things that were needed.

In the After sort interview, the boys explicitly situated themselves as a separate group to 1D and the other female pupil who began the project as can be seen in the following extract:

I: And were you all doing the coding or were different people doing different tasks?

1C: Pretty much all of us working on one thing then moving on to the next thing

I: And how many of you were working on it, how many are in the group?

1B: Us three

1C: It was us three on the coding and then [1D] and one or two others working on more of the engineering part.

1B: The electronic side of things

In the interview with the first sorts, 1D had expressed her reason for placing knowing what she wanted to do when she leaves school so highly as being because she wanted to "go into civic or aero engineering" [1D1], and had taken on a role that she felt represented that imagined trajectory within the project. She hadn't become involved with the coding side at all, but this did not appear to be because she didn't feel it was irrelevant to her role, but rather because of her perception of the superior competence of the others. When asked if she had wanted to try more programming she said:

> 1D: No because like the people that were already doing it, they were very good at doing that already so I didn't want to like start putting them off and like questioning them … because I didn't understand it I didn't kind of like want to learn about the software stuff, I just left it to the people that were able to do it.

1D's sort was considerably different with many changes to both statement positions, and relative groupings. For example, in the Before study she felt exam results were noticeably more important than learning (s11: +2, s2: -3), but in her After sort this had reversed (s11: -2, s2: 0). None of the boys had changed the relative positioning of these two statements, both 1A and 1C positioning learning as more important and 1B positioning exams more positively. 1D felt more positively in the After sort that learning about computers was important for her future, that it was about building computers and solving problems. All these statements moved from the neutral position to +3. The statements that CS is hard, that anyone can learn to program and that CS is like maths and physics also remained grouped but fell from position +2 to neutral.

A very big difference for 1D's sorts was that she could improve marks in other subjects by learning Computing. Before using the RPis she was confident this was the case (s19: +3), but afterwards she did not think this (s19: -3). This was something she struggled to explain in the interview, eventually suggesting that it was: “Because like Computing seemed to be more like maths and physics” [1D2], and that she had been thinking just about those subjects in the first sort, but in the second sort, she had been thinking about all subjects. But she had in fact placed the statement that suggests CS is more like maths and physics comparatively lower in the After sort.

1D worked quite separately from the boys for most of the project, and this is highlighted in relation to her placing how she thinks she learns through helping others, which she placed more negatively in the After study (s33: from -1 to -4), and she justified by explaining: “I work more like an individual, I learn things easier as an individual” [1D2].

Yet when asked what her favourite memory of the project was, she described a moment when they got the antenna working, which was not something she felt she had done on her own, instead she said: “It was more like a team effort because I had to connect it and they also programmed it” [1D2].

The three boys all loaded on the Geeks factor in the After study, but of course not all the changes in their respective studies were the same, as only one loaded on the Before Geek factor. The only statement that changed in the same way for all three pupils, was the statement that those who can code and build computers are more powerful, which moved positively in all cases, in contrast to 1D who moved it down two places. 1A and 1B moved this statement up three columns, and 1C moved it positively 4 columns. He explained this by saying: “ … in my opinion you have a better chance of becoming, of getting a good job, being able to use computers” [1C2].

But 1B wasn’t able to explain why he felt this more after the RPi activities than before. As demonstrated by the change in the Geek factor theme between studies, all three boys have less emphasis on self, whereas 1D has had the opposite movement, and her sort now has more emphasis on self. The factor she was most close to loading on in the After study was Aft3 Unconfidents.

9.3.2. Scenario 2 – Early Sonic Pi

Pupil	Before Factor	After Factor
2F	Uncertains	Unconfidents
2A	-ve Uncertains	Dismissives
2B	NS	Unconfidents
2E	Dismissives	Unconfidents
2C	Geeks	NS
2D	Dismissives	Unconfidents

Table 9.4: Scenario 2 participants factor loading

In this scenario, pupils did their sorts individually, but the final sort interviews took place in pairs for practical reasons. In the Before study, pupils from scenario 2 were divided across factors Bef2 Dismissives, Bef3 Geeks and Bef4 Uncertains, but in the After study most of them, four of six, identified with Aft3 Unconfidents. 2A loaded negatively on Bef4 Uncertains, essentially identifying with an inverted version of this perspective. Only one pupil had moved to Aft1 Dismissives, and one no longer identified with any shared viewpoints. Of the four After factors, the latter pupil's sort, 2C, was closest to Aft2 Geeks, but he was the only one loading on Bef3 Geeks not to map significantly with the Aft2 Geeks factor. This would seem to be more because his views didn't change and the other Geeks' views did, as he was the pupil who most significantly loaded on Bef3 Geeks, and his Before and After sorts had little noticeable difference. In contrast, the new Geek factor had changed to show a more positive awareness of connections with other subjects (s5) and their future (s17), and a more positive view of teacher support (s32), as described above. The greatest changes between 2C's sorts were in less emphasis on exams (s11: from +3 to 0), and a view of the academic connection with other subjects (s19: from -1 to +2).

2F had two statements that moved considerably: the statement that the most important aspect of a programme is that it works correctly and s22, knowing what they want to do after school. This pupil was less sure she could improve her ability to learn in Computing, but her explanation of this related to a greater awareness of the magnitude of the subject, suggesting that as she was learning more, she was realising how much she didn't know, and this was the reason for doubts about her learning ability:

> 2F: Yeah well the more you kind of learn about it it's kind of, it's more, I don't know, it's kind of I'm not sure it's .. there's more I don't know.

She also positioned CS as being about problem solving more positively, but in the interview, it didn't appear that she felt they had been solving problems in their work with Sonic Pi:

> 2F: Well it's more about solving problems, well it's not it's, it's all about solving problems but it's more *using* them using what you've learnt from the problems not actually solving them because usually we know what to do we just don't know how to put it together to make it a programme so you're kind of just using it as it is rather than adapting anything.

2E also seemed to feel that they had only learnt "how to make a tune" rather than "how to make the computer, I don't know, do something really interesting" [2E2]. 2E was also more positive that people who can code and build computers are more powerful, and she explained her interpretation of 'powerful' as being related to being 'useful', and also was situating herself as more 'powerful' with what she had learnt:

> 2E: ... because computers are going to be, erm, you know, because technology's used like everywhere for everything so, you know, being able to programme them will

probably, you know, start to be pretty useful because not a lot of people can like do it properly.

I: Why do you think you think that now when you didn't before?

2E: Erm, when it comes to like now because you know how we took the Raspberry Pi and the computers apart so now when I'm in a lesson and say connection on my computer or my keyboard doesn’t work I know like which lead I need to check where it might be going wrong.

I: Okay so you thought that was useful, the fact that you were putting it together?

2E: Yeah.

2D had decided that the subject was harder than he thought previously (s20: from -4 to +3). He related this to how the topic was taught and to the combination of different technologies they had encountered and he specifically talked about the frustration of failure in relation to the Sonic Pi activity:

> 2D: That's what I found difficult. It’s like that in the Raspberry Pi like I could do it in my head and I could imagine a tune but whenever you put it down you could never actually write the right breaks and the right like beat in the right place so it always sounds a bit weird it never sounds like how you’d imagined it. ... it was like the difference from the Small Basic to the Apple thing back to Small Basic and then to the Raspberry Pi I think that like scrambled my brain on how to think logically with computing.

2D felt the RPi lessons were more “robotic” than the other Small Basic lessons and noted negatively the reduced freedom in the RPi activity:

> 2D: ... and then like we asked Sir so we knew how to do basic programming and then if we wanted to say make it more difficult we asked Sir and he showed us on one person’s screen then we all went away and then tweaked it to reflect our needs whereas with this it was more like ‘everyone do this everyone do that’ and then kind of just like lost interest it was more robotic than like the other lessons.

2C also related frustration specifically with the Sonic Pi software, which was less forgiving of syntax errors and had a less supportive environment in terms of reporting errors than development software they had used previously:

> 2C: ... also with Small Basic you, your writing text, hundred dot right line it pops up so you can scroll through, scroll through all the functions but with Sonic Pi like you could have like missed a letter or missed a dot and it wouldn't correct it for you, you wouldn’t really know what you’d done really.

2C, as mentioned above, positioned exams (s11) as more important then learning (s2) in both studies, but they moved much closer together in the After study (s11: from +3 to 0, s2: from -4 to -2). In the Before sort he explained:

> 2C: because I find that the grades you get is like whats going to get you into universities and stuff not like what you've remembered in your head really so its mainly like the grades that will get you like into university.

But after the RPi activities he said:

> 2C: Well I, erm, I've learnt like a lot with like, erm, Sonic Pi like that Python and, erm, that's I it's kind of like helping me like to learn more about programming languages and like when it comes to grades I am ... I don't really get a grade in like Python language or whatever so like learning about it can be good 'cos like in my spare time or whatever I like programming.

2B had similarly put these closer together with s11 still remaining at their 'most like I think' +4 position, but s2 moving from -1 to +1. She reflected on this change as being based on use, rather than academic achievement, and also that, as a pupil who considered herself academic and with sights firmly set on medical school, there was a "pressure" from this subject that was different to others:

> 2B: Yeah hmm but like, yeah because from what I learnt I can like put into other things which are like more useful but the grades I get don't count, well they do count quite a lot but like with the work it sort of like triggers everything else I've done before. Here I feel like a bit of pressure to do something else.

One pupil suggested that they were interpreting s10, the statement about understanding the technology they use every day works, differently after the Sonic Pi work. When asked about the movement of this statement (s10: from +3 to -1), 2B said:

> 2B: I know how like my phone works like I know how to use it … But I don't actually know how it works like inside like all the like technical stuff like
>
> I: So you think that's why you put it higher there you're … talking about ...
>
> 2B: I thought it meant more like how to use it whereas now it's all like confidence about programmes and stuff.

Despite the suggestion that Computing is more about "programmes and stuff" 2B also describes the subject as "down to earth" in explaining how she saw CS as more like maths and physics after the RPi work:

> 2B: I don't know how to word it, it's quite weird, it's like really down to earth and there's nothing particularly like, you know like kind of history you have to like go on a bit it's just like the facts just like what you put down that's just a word not like the same.

2A loaded negatively onto Bef4 Uncertains making the factor bipolar. The inverse representation of this factor has a strong emphasis on self in terms of theme, and in this respect is similar to the Geek factor, but the statements relating to school are more positive than either Geek factor. 2A was very confident in her Computing abilities, that she knew how to program (s1: +2), could teach others (s7: +3), could build a control device (s4: +1) and certainly knew more than most her age (s13: +4). She believed it was an easy subject (s20: -4) and anyone could learn to program (s29: +4) probably without a teacher (s31: +2). It was more important to have a program that worked correctly (s23: +1) than that it helps someone (s25: -2). 2A shared the uncertainty of Bef4 Uncertains regarding whether the subject is relevant to her and her future (s8: 0 and s17: 0), but she is more certain that it isn't relevant to other subjects (s5: -3 and s19: -2).

The pupils in this factor, with the exception of 2A, seemed to have a broader view of the subject of Computing, which had in most cases knocked their confidence and view of self-efficacy with respect to the subject. They seem to feel they haven't learnt anything with depth about Computing, more a specific use. They are not sure about how it was taught, and that being able to make the Computer do something 'useful' would be a good thing. They also found the failure inherent in learning Computing frustrating.

9.3.3. Scenario 3 – Minecraft and PiFace

Pupil	Before Factor	After Factor
3B	Geeks	Geeks
3C	Geeks	Geeks
3A	Connectors	NS

Table 9.5: Scenario 3 participants factor loading

In scenario 3, perspectives changed little. Two pupils shared the Bef3 Geeks perspective and in the After study, the Aft2 Geeks perspective. 3A moved from sharing the Bef1 Connectors perspective, to not sharing any perspective, although he was very close (0.48) to loading on Aft1 Dismissives. The changes for 3B and 3C were mostly in line with the changes in the Before and After Geek factors. Differences for 3C were that he was more confident in programming ability (s1: from +1 to -1) and that he had demoted learning more considerably (s2: from +2 to -2). Notable differences for 3B included positioning CS as a hard subject more positively, whereas in the Bef3 Geeks to Aft2 Geeks mapping, this remained the same. This hadn't stopped him from feeling improvement had been made in the short time span of the activity: "I did think it was quite complicated because there were a lot of instructions for it to set up but now it just comes naturally" [3B2].

Also remaining the same for the representative perspectives was the priority for programming being working correctly or helping someone. But for 3B, although initially agreeing with the Geek perspective that working correctly was the priority (s23: +3 and s25: -1), this switched for the After study (s23: 0 and s25: +2).

Unlike others who identified with the Geeks factors, 3C had computing ability as conferring power both Before and After the RPi activities, placing it at the highest +4 position. When asked about this he explained:

> I think because it's like we're going into a digital age I think programming is going to be an essential tool, erm, I feel it is it is you (pause) ... Erm, I think just like if you learn how to programme to a certain standard the amount of things you'll be able to do and just really, I don't know (laughs) so much greater than if you didn't [3C2].

3A has an increased focus on self and school and has moved subject related statements to a lower priority. He has more confidence in being able to teach others how to program and that he knows more than others his age, (s7: from -2 to +2 and s13: from 0 to +3)) that he learns through helping others, (s33: -3 to +1) and that people can learn to program without a teacher (s31: from 0 to +4). He doesn't believe it is such a hard subject as before (s20: +2 to -2). He has also reversed s23 and s25, but the opposite direction to 3B – he now believes working correctly is the priority (s23: from -1 to +2 and s25: from +4 to +1). But 3A has lost any sense of personal relevance of the subject: he believes less that learning how computers work is useful for his future (s17: from +4 to +1) he doesn't see relevance to other subjects (s5: from +3 to -1) and he thinks less that people who can program are powerful (s3: from +1 to -4) or can make the world a better place (s9: from +2 to -1). He didn't really see any advantage to using an RPi over a PC claiming that the only benefit was: "I guess its quite nice and small" [3A2].

3B's perspective on the nature of CS remained the same, with building computers as the least relevant and problem solving as the most. 3A changed from believing problem solving was the least important and software creation the most, to placing all aspects equally. 3C initially had building as least important, then problem solving with software as the most important, but changed this order to place problem solving as the priority.

9.3.4. Scenario 4 – Later Sonic Pi

In this scenario, the pupils performed both the sorts online during class time, providing written comments about their extreme statements for both sorts, and then were interviewed in small groups after the second sort. Three of the four males (out of a total of fifteen participants) did not load significantly on a factor in the Before study. The only one who did, 4D, identified with Bef4 Uncertains. Following the RPi activities, this pupil no longer identified with a shared perspective, and one other male continued not to, 4M, but the other two males now shared perspectives Aft3 Unconfidents and Aft4 Learners. Additionally, three of the female pupils no longer identify with a shared view. A third of the pupils identify with Aft1 Dismissives, only one with Aft2 Geeks and two with Aft3 Unconfidents. The

Aft4 Learners factor has just two participants loading on it, both from this scenario, one male, 4K and one female, 4O.

Pupil	Before Factor	After Factor
4A	Geeks	Geeks
4O	NS	Learners
4M	NS	NS
4B	Dismissives	Dismissives
4C	Dismissives	Dismissives
4E	Uncertains	NS
4F	Uncertains	NS
4H	Connectors	NS
4G	Connectors	Unconfidents
4I	Connectors	Dismissives
4J	Connectors	Dismissives
4N	Dismissives	Dismissives
4D	Uncertains	NS
4L	NS	Unconfidents
4K	NS	Learners

Table 9.6: Scenario 4 participants factor loading

The only pupil from this scenario loading on Bef3 Geeks and Aft2 Geeks was 4A, whose perspective generally changed in line with the changes of those shared perspectives: she became less certain, but still positive about her ability to build control devices (s4: from +4 to0) and to teach others how to program (s7: from +4 to+1), and less certain that anyone can learn to program (s29: from+3 to -3), but did feel more positive that she knew more than others her age about the subject (s13: from -1 to +2). This pupil showed in her comments that she had worked on electric circuits with her Grandfather, and regarding her placement of her ability to teach others as one of her two most positive statements, she claimed:

> I was the first person to complete the HTML and CSS course on Code Academy and I have gone on so I know how to write some programs and I think that I understand it [4A1].

In her After interview, in discussing why she felt the statements about building devices and teaching others programming were less positively positioned, she felt this was because at the time of the first sort she had just been doing the projects with her Grandfather, and now felt it “also depends what the device is” [4A2]. Regarding why she now felt significantly less positive about whether anyone can learn to program, she said:

> “Yeah because it depends whether you want to because if you apply .. if you don’t apply yourself then you’re not going to learn and all depends on if you want to or not” [4A2]

Similar to 3A in scenario 3, the only pupil in scenario 3 not to load on the Geek factors, 4A1 has reversed the statements on the priority in programming, from placing helping somebody as more important (s25: from 0 to -2) to placing working correctly as more important (s23: from -1 to +1).

Those moving from Bef2 Dismissives to Aft1 Dismissives show little change in their views and there does not seem to have been much impact on their perspective through the Sonic Pi work. These pupils are 4B, 4C and 4N. 4B is still fairly certain about what she wants to do when she leaves school (s22: +3 in both sorts) and continues to place s17, whether Computing has relevance for her future, at -4. She explains:

> I think computer science is not so important for my future because in my future i would like to be in the performing arts which doesn't include computers. [4B2]

4N similarly stated: “I don't think that I want to do a job that involves programming computers” [4N2]. 4B2 sees relevance to other subjects as even less important (s5: from +1 to -3), but in her interview she made it clear she was focusing particularly on the RPi, rather than her views of Computing in general: “Because in some subjects like if you talk about the Raspberry Pi in some subjects it doesn't really it doesn't really help if you know what I mean if that makes sense” [4B2].

4C also sees even less relevance to other subjects (s19: from -2 to -4) and when asked about this claimed that “no, because in science, you don't need to program stuff if you become an astronomer or something else” [4C2]. However 4B does seem to believe she has learnt something that perhaps her peers might not know, in suggesting she moved s13 from -3 to -1:

> Because learning about the Raspberry Pi I know how to build it to actually use it like and I learned how to use different things on the Raspberry Pi as well that most children my age won't know how to use. [4B2]

This view that they had learned to build something was echoed by 4C, who described their RPi work as “a new area of IT” [4C2], and when asked how it was different to their previous IT work, explained, “you had to like build it to like use it” [4C2]. This ‘building’ element led 4C to position s4, regarding whether the sorter felt they could build a control device, at a lower position in her After sort (s4: from +1 to -1):

> I don't know probably because it was more complicated than just doing it on the computer because you had to plug it in and then work out the links end everything. [4C2]

4I and 4J moved from Bef1 Connectors to Aft1 Dismissives. The changes in their sorts are generally similar, with for example, a stronger view of Computing as being like maths and physics, and both now believing that a program helping someone is very important (s25: +4), but with 4J placing s23, that a program works correctly as equally important, whereas 4I placed this at 0 in her second sort, moving up from -3 in the first sort.

Two statements changed in noticeably different ways: 4J reduced the importance of CS being about building computers, (s12: from 0 to -3), whereas 4I increased this (s12: from -4 to +1). In her Before sort she had explained the extreme positioning of this statement by suggesting: “I don't think that is true. I think it is about inside of computers and how they work” [4I1].

4J believed more that she learned through helping others (s33: from -1 to +2) whereas 4I believed this less (s33: from +3 to 0). 4I explicitly described influence from friends and family on her sort. For s21, whether people into computers are seen as geeky, she placed this as -4 on both sorts and explained: “No because my brother is into computers and he struggles academically and he is not at all geeky” [4I2]. With regard to her high placing of whether people can learn to program without a teacher (s31: +4), for the Before sort, 4I said: “My friend has completed Code Academy and she hardly needed any help. People dont have to have a teacher to learn” [4I1]. In the After sort she placed this statement at a lower position (s31: +1), but wasn’t able to explain her change in view.

4G was the only pupil across all scenarios to originally identify with Bef1 Connectors and then with Aft3 Unconfidents. The statements around which her perspective most changed were whether being a computer scientist means being good at talking to people (s34: from -4 to 0), whether people who can program are more powerful than those who can’t (s3: from -2 to +2), and whether they are seen as more geeky (s21: from -2 to +1). She also believed it was more important for a program to work correctly after the RPi work (s23: from -1 to +3). Statements that she now identified less with were whether her friends would be interested in the RPi work (s6: from +1 to -2), that Computing is more like maths and physics than social sciences (s26: from +1 to -2), that anyone can learn to program (s29: from +3 to 0) and whether she understands the technology she uses every day (s10: from +1 to -2). Her extreme positive views did not change after the RPi work and she was still adamant that people who can program could make the world a better place, before and after the RPi work explaining this in relation to supporting those with disabilities: “I definitely think this because people are constantly creating new things that can help people to do things e.g. they made special robotic arms for people with no arms or self driving cars” [4G1]. She also kept the emphasis of the subject as being problem solving, suggesting before the RPi work that this was, “because when we did Code Academy we had to solve lots of problems” [4G1] and afterwards, “I think that when you are programing a computer, you might make mistakes but not notice them, then have to solve the problem of why the computer won't work" [4G2].

All the pupils identifying with the Bef4 Uncertain factor, no longer loaded on a shared perspective after the RPi work. 4D (at 0.46) and 4F (at 0.39) were closer to loading on the Aft1 Dismissives than any other factor, and 4E (at 0.43) was closer to Aft3 Unconfidents. All the positive views about the RPi work expressed by 4D were related to the hardware aspect of the work, and connecting the board and peripherals, which he had clearly enjoyed. He was much more confident that he now knew more about computers than others his age due to this experience (s13: from-3 to +2). He was more positive about both using what he had learnt in the future and his understanding of everyday technology (s8 and s10: from -2 to +3). He no longer thought that helping someone was the most important aspect of programming (s23: from +1 to 0, and s25: from +2 to -2).

The biggest changes for 4F were the importance of exams (s11: -1 to +4) and thinking that anyone can learn to program (s29: -3 to +3). Also she no longer saw Computing as more like maths and physics than social sciences (s26: from +3 to -3) and explained this as:

> 'Cos like, like when you programme the computer it's like nothing like any other subjects because you have to like remember how everything goes and make sure everything's perfect and everything but if you like … if its not perfect in maths or physics then it can still work sometimes [4F2].

She was much less sure that she learned more from teacher talk than from doing an activity (s32: from +4 to -2). She was confident that using technology equated to understanding how it worked before the RPi activity (s10: +4) and this changed very little after the study (s10: +3). She explained this was "Because I go on my phone everyday so I understand how it works" [4F2].

The primary changes for 4E were whether people can learn to program without a teacher, which after the RPi activities she felt much more positive about, (s31: from -3 to +2), as she did regarding how well she understood every day technology (s10: from -1 to +3). She felt very much more that she learned more from doing activities than from teacher talk (s32: from +4 to -3). She was less convinced that Computing is more like Maths and Physics than social science subjects (s26: from +1 to -3), which she struggled to explain, but said, "Because… I don't know I don't think they're more like than history and... but I don't think that they're more like it than maths and physics I think they're all the same" [4E2].

Neither 4K nor 4O loaded on a factor before the RPi work, but both identified with Aft4 Learners afterwards. 4O was close to loading on Bef1 Connectors at 0.47. The changes made by these two pupils are therefore quite different, with the exception of statements 5 and 11, which they both felt more negative about, and both kept in the same relative position. Statement 5 is the relevance of what they are learning to other subjects, which 4K moved from +3 to -2, and 4O moved from +2 to -1.

Statement 11 is the priority of exams which 4K moved from +3 to -2, and 4O from +1 to -2. 4K explained his less positive view of s5:

> Erm, if we'd learnt a bit more maybe about the actual programming side and more about the part of instead of just doing the little sound thing I think that would have been a little more relevant but I mean it's the way that you approach it [4K2].

4O had considerably altered her view that she could learn more through helping others (s33: from -3 to +4) and while unable to say what had changed her view, she simply now suggested: "I think that I could learn more from other people" [4O2]. She was also more positive that her friends would learn from working with her too (s28: from -3 to +2). But she was much less confident in her ability to build a device (s4: from 0 to -4) or in understanding how the technology she uses every day works (s10: from +4 to -2). In her Before sort, she justified positioning this as most like how she thought with: "I think that it is important to know how your phone works so in the future when your phone breaks you might know how to fix it" [4O1] suggesting she was not in fact relating the statement to her existing understanding but to the importance of having that understanding.

4K had a number of changes and was among the more reflexive of pupils during the process of the sort. With regard to his reduction in certainty that he could teach others how to program (s7: from 0 to -4) he explained, "Yeah I think I knew, thought I knew a little bit more than I did, I think" [4K2]. On comparing his sorts, he also decided that in one instance, whether he learned more from teacher talk than doing activities, he actually agreed more with his Before sort, where he had positioned this at -4, than the sort he had just completed, where he placed it at -1. He explained:

> Well it is for every lesson really I mean if, if you're just listening to the teacher for the whole lesson you're not really fully concentrating properly so I think it is better if, you know, if you're doing something in a group or doing an activity that's stimulating more [4K2].

He was much less certain that he understood the technology he used (s10: from +1 to -3), and was more convinced that it is more important to be able to use computers in many ways than to program them, (s27: from +2 to +4) however he explained that he saw use as a necessary precursor to deeper understanding:

> Yeah I think erm, that if you can use it and maybe not know that much how to program it you could teach yourself maybe if, if you know how to use it, how to program like so I think if you know how to use it first that's better to start off with than just knowing how to program and not knowing how to use it [4K2].

4H identified with Bef1 Connectors, but after the RPi work did not load on any factor. However she was close to identifying with both Aft3 Unconfidents (at 0.46) and Aft4 Learners (at 0.46). The greatest difference in her sorts were whether her friends would be interested, which she now felt would not be the case (s6: from +1 to -4) and that she did not believe the subject was as hard as she had previously believed (s20: from +3 to -1). Any interest she might have had before the RPi work had been lessened: “My friends are not interested in Computers and neither am I, so I don’t think they will be impressed!” [4H2]. But she still was certain learning about computers was important for her future (s17: from +3 to +4) and claimed this was: “Because in the future people will be using technology more and more” [4H2].

4H had a very strong imagined trajectory, with knowing what she wanted to do when she left school being the most strongly positive statement in both sorts, and similar comments made about this in both the Before and After study:

> I want to go to Oxford or Cambridge with [4E] and we will study medicine and then I will become a surgeon or a General Practitioner. I would like also like to be a specialist in the Circulatory System [4H2].

She felt more that Computing was like Maths and Physics than previously, (s26: from -2 to 0) “because like what we are learning about was like with numbers and like and I think maths and physics is more to do with numbers then history and sociology” [4H2].

4L did not identify with any factor in the Before study, but then loaded on Aft3 Unconfidents. Like 4H, 4L also moved statement 26 to suggest he felt Computing was more like Maths and Physics than he had previously, (s26: from 0 to +2) explaining, “I thought it was a bit more like, you had to work things out a bit harder, think a bit harder about things you do rather than reading things and learning from it” [4L2]. This was related to how he had changed his views of the focus of the subject, from being mostly about software, with hardware and problem solving equally relevant, to being predominantly about building computers and less about problem solving:

> Er, because I think like science, you know, you like build stuff and work things out in science you use like formulas to work stuff out, I think that’s what you do in building hardware. Yeah. [4L2].

He had few significant changes between his sorts but compared to what he thought before the RPi work: he did feel CS was a harder subject (s20: from -1 to +2); that being able to program could not help make the world a better place (s9: from +3 to 0); that he could not improve his marks in other subjects through Computing (s19: from 0 to -3); and was less confident that he knew more about computers than others his age (s13: from -1 to -4). He explained this latter change saying:

> I just thought when I was looking round the room and looking how much people had done compared to me I thought people had done more .. and done more complex stuff compared to me [4L2].

4M did not load on a factor on either study, was not close to any factors and showed no theme pattern in his sorts. His sorts had completely changed but he was not able to explain this as he was one of the pupils not available for interview following the After sort due to a disciplinary meeting with the department Head during that time.

Chapter 10 – Discussion of results

I use the words you taught me. If they do not mean anything any more teach me others. Or let me be silent. (Beckett, Endgame)

We must become ignorant of what we have been taught
and be instead bewildered.
(Rumi, Bewilderment)

Introduction

The first two research questions of this thesis were:

- How can we use a social theory of learning to frame the processes and outcomes of "criticality" in order to inform better learning design in Computing education?
- How can the incorporation of Raspberry Pi technologies in learning design support development of learning citizenship and knowledgeability at school level?

In the first half of the thesis I presented a critique of existing language in the research literature and policy reports, and advocated for abandoning terms such as critical and computational thinking and literacy, instead proposing terms drawn from social learning theory, such as knowledgeability, learning citizenship and competence. In this chapter I will summarise the results presented in chapters seven, eight and nine with respect to the changes in perspective that occurred around the RPi learning activities in the four scenarios and what these changes suggest with regard to the participants' developing experience of knowledgeability and learning citizenship. I will use the combination of data from observations and the analysis of the two Q studies to explore what elements of the learning scenarios and the individual experiences within those scenarios I believe may have been instrumental in influencing these changes in positions of knowledgeability. For each scenario in turn, I will firstly summarise the results from the previous two analysis chapters with respect to the contextual data presented in chapter seven, before discussing the implications of these findings in terms of the relevant themes in the literature discussed in the first half of this thesis. This discussion will explore the impact of these early implementations of the RPi in classrooms with reference to the themes of Papert's Logo work, which he termed epistemological pluralism, constructionism and technocentrism, around which the respective substantive, theoretical and methodological research questions were framed from a social theory perspective. Following this, the final chapter will extend the response to the first question, reflecting on the research project to answer the third and final question:

- How can Q methodology be employed to explore the growth of knowledgeability and learning citizenship in pupils of Computing, and how can the methodology itself support development of these concepts?

Before this discussion, it will be useful to recap briefly the constructs from that theoretical framework that have been explored in this project, and how the methodology was designed to investigate these processes, before exploring them in detail over the next two chapters. I have posited the notions of knowledgeability and learning citizenship as constructs that encapsulate criticality, but which work in a dialectical way with notions of competence: where criticality and skills are not separate entities or processes but where the experiences of each are integral experiences of becoming, of identity, and so one cannot change in isolation from the other. This avoids a hegemonic view of thought over activity and these constructs do theoretical work in such a way that avoids the objectification of notions such as computational and critical thinking discussed in chapters 3 and 4. These constructs are also inherently perspectival, being processes of locating oneself in practice and the methodology was also informed by a locational view of self, learning and becoming. Knowledgeability is:

> "… a process of modulating identification across multiple locations of accountability. This involves a constant interplay between practices and identities. In a complex landscape, trajectories of practice and identity do not evolve in parallel. The two act as distinct but interdependent carriers of knowledgeability across time. Learning takes place when they dance" (Wenger, 2010, p.7).

Learning citizenship is the ethics of how we invest our identities into the learning spaces we experience. Each Q sort captured, for one pupil, a discursive representation at a moment in time of how they locate themselves within the landscape of being a student of Computing in their particular school context. This tells us which sources they feel most accountable to within the regimes of competence that include education, their own local context and the practice of Computing at that time. Exploring how this process of location has changed for the pupils following the RPi work, suggests how their trajectories have been carried and altered over that time. The combination of a reflective discussion informed by comparing these locations, and observations of the work done, implicitly asks the pupils to acknowledge the fluidity of self and explicitly account for the changes in their perspective with respect to factors of their learning experience.

The substantive research question this project aimed to address was how learning designs incorporating the RPi might support the development of knowledgeability and learning citizenship during competency driven activities. In acknowledging that the exploration starts with a learning context that incorporates a technology, rather than starting with the technology itself, the implementation of Q methodology that I have used focuses on the wider context of the learning situation with respect to levels of individual and collective and thus avoids the technocentrism Papert claimed influenced research on the impact of Logo.

10.1. Four learning designs with the RPi

The four scenarios observed in this study were related through the use of an RPi in all the learning activities. I describe the observations of each scenario in chapter 7, but to summarise the key elements here, two scenarios were essentially enforced on the pupils, taking place in class time, one was a holiday club, so may have been more or less enforced through parental influence, and one was an after school club, so pupils had chosen to attend, although obviously parental influence may have played a part in this choice also. In this way, the class time activities were aimed at a tourist audience and the holiday and after school club, more towards sojourners, those with some sense of an inward trajectory into the practice of Computing.

10.1.2. Scenario 1

Scenario 1 entailed less directive teaching than any of the other scenarios. Essentially pupils were given the outline of a project and then to a large extent, left to their own devices, and intervention was requested when needed. Three of the four participants from this scenario had considerable coding skills for their age before starting the project, but the coding required for the project was harder than for the other scenarios, so the learning curve required was relatively similar to other scenarios for three of the four pupils. For the fourth pupil with limited coding skills, the coding element of the project was inaccessible to her, and there was no support, either from the teacher or other pupils, offered to engage her in this aspect. The hardware and interfacing elements of this scenario were also considerably more complex than any other.

The pupil that identified with the Bef3 Geek factor remained on the mapped Aft2 Geek factor, and the other two boys, who before the project had not identified with any shared perspective, now also identified with the Aft2 Geek factor, but as I have shown, despite a clear relation between the two factors, there were noticeable differences in the two Geek perspectives, in the lesser focus on self and increased connections at all levels for the After study. In this scenario, developing doubt about their competence, or differentiating competence with respect to hardware and software, (indicated by relative positioning of statements about programming and building devices) is relative to expanding awareness of what the regime of competence of Computing entails. The latter was evidenced by the reduction of the position of how well they think they understand the technology they use everyday for every participant from this scenario. Given that the two Bef3 Geeks from scenario 3 and the one Bef3 Geek from scenario 4 also continued to load on the Aft2 Geeks, it would suggest that for those who felt accountable to the subject of Computing before using the RPi, their experience with the RPi had a similar influence, regardless of the differences in learning context in scenarios 1, 3 and 4. Only the one pupil from scenario 2 who loaded on Bef3 Geeks no longer shared this perspective, which I will discuss below with respect to scenario 2.

Pupils in this scenario were confident in their ability relative to their peers, so their identification with the subject in this respect has not been undermined. In the case of the pupil who loaded on the Before Geek factor, this relative perception of competence increased, as it did for 1B. For 1C, this was already placed at the most positive position and remained so. For 1A, his broader understanding of what the subject entails that led to more doubt in his personal competence, his positive understanding of the relevance to other subjects, and greater belief that they can improve how they learn about Computing, I would suggest are encouraging developments in a position of knowledgeability, in the same way as for the other pupils sharing the Before Geek perspective. The similar increase with respect to the statement that programming and power are connected may also support this, although the only pupil from this scenario to explicitly define his interpretation of power related it to the ability to get a job, so this move may have been based on purely utilitarian interpretations.

Of the four After factors, 1D was closest to loading on two factors: the Aft2 Geeks and the Aft3 Unconfidents, whereas previously she had been uncertain about what Computing was and how it was relevant to her. This suggests her experience with the RPi work still led towards a greater breadth of understanding of the subject, but she remained lacking in confidence about her own abilities, except with respect to the specific activity of building a control device, which she felt more positive about. 1D defined her own competence relative to the others in the group, and didn't feel able to participate in the coding group, but despite this non-participation, she continued with the project and it was not an experience of marginality as she believed she had a genuine role to play as the engineer of the project: the activity design allowed her to express her strong imagined trajectory into engineering.

10.1.3. Scenario 2

In scenario 2, pupil 2C shared the geek perspective initially, but whereas the other pupils with a Geek perspective altered their views, there were very few changes to 2C's perspective. 2C and the pupil he was partnered with had less interaction with the rest of the class than any other group. The two pupils, 2D and 2E who had been dismissive of the relevance of Computing, having strong views on what they would do in the future, and not much confidence in their abilities, now shared the Unconfidents perspective – they had even less confidence in their abilities, but could see more relevance to their future and could see more that programming skills might enable someone to help make the world a better place and to be more powerful.

The two pupils who were unsure about the relevance of the subject before working with the Sonic Pi resources, were 2A and 2F, the former of whom shared the Dismissives view in the After study, and the latter who moved to the Unconfidents view. 2A, who represented the inverse of the Bef4 Uncertains, was the most confident in her abilities in Computing of all the participants in all scenarios, but shared the uncertainty of the relevance of the subject. While her confidence in her abilities was considerably reduced, and she was now negative about the relevance to her future, she could see connections with other subjects and had reversed her view on the importance of helping others with a program being more important than it working correctly: after the Sonic Pi work, she felt helping someone was the priority.

The reduction in confidence for all in this scenario can be seen across the pupils in the movement of statement 4, whether they believed they could build a control device, the position of which four pupils reduced and the other two left in the same negative position. This was not just a greater awareness with respect to hardware as, similarly, the position of statement 7, regarding their ability to teach someone else to program, was also reduced by four pupils, stayed the same for one and was increased by one. The connection between Computing and other subjects was seen more positively by four pupils, remained the same for one and went down for one. Despite the loss of confidence experienced by pupils in this scenario, the pupils' identity as good students remained very similar, in positive positions for all pupils, with four leaving this in the same position, one moving it up one place, and one moving it down one position.

This scenario entailed a classroom based, timetabled lesson, using the Sonic Pi material that aims to teach computational principles through creating music. As a relatively small class (twenty two pupils), there was room to move around the learning space to support and view the work of others, which the teacher did not discourage, though the layout still limited the implementation of the unplugged activities. The small class size also meant that most of the groups collaborated, and engaged in friendly competition. The curriculum of practice in scenario 2 was more negotiable than the most similar of the other scenarios, scenario 4, which used the same resources and was also a timetabled lesson. The teacher in scenario 2 would appear to have been more disorganised: he was often late having been attending leadership team meetings; other than the first lesson he was reading the lesson plans as pupils were setting up their RPis, having not prepared previously; and he left resources for a cover teacher that had already been completed for the one lesson he missed.

However this teacher readily adapted the resources with responsiveness to the learning situation, and was happy to abandon the plans for a particular activity even as they were being used, if he did not believe the pupils were gaining from it. His judgement on whether this was the case was based on an established relationship with these pupils in his position as a member of the SLT and a long term member of staff, evidenced in knowing all pupils' names and interests, and incorporating this into the activities heavily, even prioritising this over the stated objectives in the lesson plan. For example during the time pupils were working at their screens, there would be more discussion about musical composition than computational concepts with those pupils with musical interests: the computational constructs were brought in as means to achieve the musical ends. Opportunities were thus provided for pupils to express their competence from other areas of their landscapes. He explicitly asked pupils to use the imagination process of identification in connecting concepts discussed with prior work in Computing and to music interests both within and extra curricular. He had a personal interest in music himself, and was comfortable using the language of music to explain the related Computing concepts, such as the lesson on concurrency, which combines a melody and baseline.

10.1.4. Scenario 3

Similar to scenario 1, the two pupils in the Minecraft Pi and PiFace scenario shared the Geek perspective before the RPi work, and then demonstrated changes in perspective that suggest more doubt in their own competence and a greater understanding of the breadth of the subject. The third pupil in this scenario was very close to the Aft1 Dismissives perspective, and had reduced the connections he saw between Computing and other subjects, and for his future. Working independently in the holiday club environment, for this pupil, had led to an increased conviction that one could learn to program without a teacher, whereas for the other two it had the opposite effect. All three pupils thought more positively about working with other pupils in groups, as evidenced by all pupils increasing the priority of learning through helping others, and also increased or the same positions about learning from other pupils and contributing to group learning themselves.

The key difference between this scenario and the other three was the short but intense time span of fourteen hours over two days. After the initial demonstrations given at the start of each day, the pupils received help when it was requested, but were otherwise free to work at their own pace and as a holiday club, the formality was considerably less than these pupils were used to. The only activity all pupils were asked to complete was using the PiFace interface board with Scratch and Python, following which all chose the Minecraft Pi over the Sonic Pi option. As in scenario 1, where an existing identification with the subject was evidenced in the Before study, this use of the RPi in an open ended learning design has had positive effects on knowledgeability, creating a better understanding of their own competence with respect to the regime of competence of the practice of Computing, a more positive approach to contributing to their learning community and learning through helping others, and an awareness of connections between Computing and other subjects.

However where the existing identification was not as strong, in this scenario the pupil had a different experience of knowledgeability, being now less aware of the connections with other subjects, its future importance and relevance to their own trajectory.

10.1.5. Scenario 4

In scenario 4, the teacher was very organised and had been through each lesson with the equipment beforehand. He was understandably wary of the potential technical issues during the lesson. He adhered to the content of the given resources and when pupils became less attentive, he employed behaviour strategies and did not adapt the materials significantly. As described in chapter six, he was relatively new to the school, and appeared unused to low level disruption, which was generally considerable from this group for a school of this nature, although still minimal relative to many contexts. From conversations with both teachers before and after each lesson observed, the teacher from scenario 2, with his seniority and having completed a PhD himself, seemed more at ease about having an observer in the classroom. The teacher in scenario 4 may have felt more obligated to stick to the planned resources partly because of my presence. Due to being in the school only a short time, he did not know the pupils well, but did still attempt to draw out ideas from those pupils who had an existing interest in music.

In scenario 4, the dynamics of the classroom space meant moving about the room was very limited and pupils were encouraged to stay in their seats, but nonetheless, we saw from 4L in the previous chapter that he defined his own competence relative to the other pupils around him. In both scenarios 2 and 4, the teacher instigated a competition to create a piece of music, but in scenario 4 only at the end of the lesson were pupils able to hear the work of their peers, whereas in scenario 2, pupils frequently moved about to hear the developing compositions of their peers. This was not possible in scenario 4 with the limited space.

The pupil identifying with the Bef3 Geek factor in this scenario, followed the pattern of all but one of the other Geeks and shared the Aft2 Geek factor, suggesting her position of knowledgeability had developed positively as it did for all on this factor, irrespective of the differences between scenarios 1, 3 and 4. The majority of the pupils who did share a perspective became more dismissive of the subject, not demonstrating much change in their views of their own competence, except as relative to their peers.

All the pupils in scenario 4 who began from a perspective of being dismissive of the subject, remained dismissive, although again, there is some consideration shown from them that they have learnt something that others may not know because they have 'built' something. One pupil, who previously saw the importance and relevance of the subject but felt they were not competent in it, became dismissive of Computing. Those who were not sure about the subject in terms of relevance and their own competence, but who were strongly aligned to the school regime of competence, no longer shared a perspective in the After study. The statement that was moved in the same way by the most number of pupils was statement 5, that they can see relevance to other subjects, where nine pupils placed this more negatively after the Sonic Pi work, five left it the same and one pupil moved it more positively but only by one position. Eight pupils in this scenario felt more positive after the RPi work that they understood technology they use everyday, and seven felt less positive. Eight pupils became more sure that they knew more about Computing than their peers, and five felt equally sure about this after using the RPi. In this scenario, with the exception of the pupil loading on the Geek factors, it would seem that the position of knowledgeability is at best unchanged or has become narrower.

Unlike the other three scenarios, where the pupils' view of themselves as good students mostly stayed the same, with just two pupils across all three of those scenarios reducing the position of that statement, in scenario 4, pupils' identification with being a good student had reduced in seven cases. Just two pupils in this scenario identified more with being a good student in the After study, and one of these was 4A, the only pupil in this scenario to identify with the Bef3 Geeks and Aft2 Geeks. Thus during the time the pupils worked on the RPi activity, not only did most of them become more dismissive of the subject, but their identification as a good student was undermined.

10.2. Learning design and trajectories of knowledgeability

The various learning designs with RPis tended to align perspectives of the pupils experiencing them, but whether or not the movement indicates positive developments in knowledgeability depends on the starting location of the individuals within each scenario with respect to being a Computing pupil, and their experience of the pedagogy through which it was delivered. For those who started from the Geek perspective, other than the pupil in scenario 2, there appears to have been growth in knowledgeability and the positive movement of learning through helping others, despite less assurance in their own competence of working in a team, is a sign of positive learning citizenship. The small increase in position of whether programming can help make the world a better place also may indicate an improved knowledgeability in terms of seeing the potential in developing their Computing competence.

The key differences between the experience of the pupil in scenario 2 who did not load on the After Geek factor, 2C, and the other participants who remained on the Geek factor, were that 2C decreased the position of the importance of Computing for his future. In his interview he explained that he had not got room in his options to take Computing as well as the other subjects he wanted to do, and increased the position of whether learning Computing could improve marks in other subjects from a negative to a neutral position:

> P2: Well, that's also because I like I really want to do computing next year but I don't have enough like option spaces to do it ... like and in a way that's made me more sure because now I'm like quite certain about how I want to be like a doctor GP... and in fact I'm more sure now like ...
>
> I: Because you've had to think about your options is that ...?
>
> P2: Yeah and like I really wanted to carry on with Computing but I couldn't because there wasn't enough option choices

The process of choosing options for GCSEs, which had happened at the same time as the latter half of the RPi work in this scenario, had forced the pupil to consider his future trajectory, and he was more certain than ever that he wanted to be a GP and that he did not see the relevance of Computing to this career. In addition, his view had been affected by learning another software tool, Gamemaker, in his spare time with a friend. He used this purely as a screen based tool and there were no hardware aspects other than the PC he ran it on. This pupil also worked less collaboratively than other participants from scenario 2, only working with his partner and suggesting, “I haven't really been talking to anyone throughout it like I've just been on a computer typing it up, I didn't need to speak to anyone” [2C2].

Imagined trajectory thus appears to be a stronger factor in the experience of these participants than the pedagogy within each learning design. However scenario 2 and 4 do appear to have had different effects on the pupils who didn't already have a strong sense of accountability to Computing. There are also interesting differences between the two extra curricular scenarios, where in scenario 1, the non Geek does start to align more with the expanded knowledgeability Geeks, but in scenario 3, the non Geek became dismissive. I will now look at the themes that emerged in the literature in the first half of this thesis to explore what may have led to these differences.

10.3. Hegemony of the abstract

diSessa was concerned that while use in social practice was the basis of literacy, “socially oriented literacy studies have backgrounded or even dismissed the contributions of the props of literacy, its technology” (2008, p.242), while in contrast, Papert was concerned that as a tool for developing meta-cognitive abilities, the technology of Logo was central to explorations of its effectiveness in a limiting way. Further, Turkle and Papert believed computers were seen as the embodiment of the abstract and that, “The practice of computing provides support for a pluralism that is denied by its social construction” (1990, p.1). As shown earlier, Logo was originally used in Maths education, but became instrumental in the development within schools of a subject in its own right of computer studies. The RPi is a tool aimed at supporting learning Computing for its own sake. However I have proposed that in its position as a boundary object the RPi could be used in learning design to support Papert’s goals, where the latter are recast from a social theory perspective.

Logo and Boxer were predominantly screen-based tools, but Logo was accompanied by the Logo turtle, and the physicality of this is something Papert suggests is important, through activities such as ‘playing turtle’, where pupils are asked to move their bodies to create a circle before programming the turtle to do so (1980, p.58). He suggests that:

> “… relating science to physical skills can do much more for learning science than providing what educators like to call a "motivation." It can potentially place children in a position of feeling some identification with scientists through knowing that scientists use formal descriptive languages and knowing that they too can use such languages as tools for learning physical skills - juggling for example. The idea is to give children a way of thinking of themselves as "doing science" when they are doing something pleasurable with their bodies” (ibid, p.97)

Both Logo and Boxer are software tools that aimed to teach computational ways of expressing scientific and mathematical principles through the capacity of computational models. The RPi in contrast is a piece of hardware around which learning activities have been designed to provide ways in to understanding computation itself. It is then the learning designs and projects the RPi facilitates that will or will not achieve the aims of the RPi Foundation. The degree to which the activities explored in this project connected physical and metadiscursive levels of competence varied.

The Sonic Pi activities have the least emphasis on embedded Computing. The Sonic Pi software can also run on a PC or Mac, so once the RPi was set up, there was little in the activity that explicitly connected the computational concepts with the physical board. The Sonic Pi activity does use computational concepts to orchestrate and express musical principles through sound. The PiFace activity was explicitly designed as an embedded Computing exercise that uses computation to create an interface between the physical board and the onscreen responding animation: if I push button A, the onscreen character moves to the left. The Minecraft Pi in scenario 3 was screen based, and took a virtual world and its rules that pupils were familiar with, and gave them control over those rules through computation. The Pi in Space project was much broader in scope, including the connection of additional physical components to the device of which the RPi board became a part. However the board itself essentially acted as a control unit of the other components. There was no intention of this activity to teach computation, but computation was needed to tell the board how to control and communicate with the other components.

The physicality of the RPi was an important aspect of the learning in all scenarios regardless of what the main activity aims were. In scenarios 1, 2 and 4, an increase in confidence with the hardware was observed over the weeks as pupils simply repeated the process of connecting the RPi equipment at the start of each lesson and reconnecting the school's workstations at the end of the lesson. As part of a generation that has experienced increasingly black-boxed technology, this physical relation to the equipment was clearly a novelty for the pupils. Even those in scenario 3 performed the set up more quickly on day two of the holiday club. These pupils had been using PiFace on the first day, which had involved some reconfiguration of their equipment. A pupil from scenario 2 described this change in the setting up process:

> It was it wasn't too bad. Well yeah it did like the first couple of lessons it was you're like 'ah that lead goes where?' and then after that just you're like 'de de de' [2F2].

They seemed to appreciate this physicality over previous screen work also, with one pupil suggesting, "It was more interesting … to see the little chip thing. It was more interesting I was like 'oh this is fancy'" [2E2]. Pupils related this physicality to use, in positive ways even within scenario 2, which required less hardware activity, with 2E suggesting they had simply learnt to make a tune rather than "do something really interesting" [2E2), but believing the learning they had achieved in connecting devices would be useful. 2E's comments suggest she had seen a glimpse of what might be possible through using the physical board, but they hadn't really exploited its potential. In the same scenario another pupil had redefined the way they interpreted "use" in positioning statement 10 for the After study.

One pupil struggled to situate the subject, suggesting it is "down to earth" and there was "nothing particularly like it" despite having positioned s26 to imply she now thought it was more like Maths and physics than previously. I showed how the idea of the use value connected to the statement on ability in Computing conferring power, by 2E, is defined relative to others: she saw that having a skill that, in her view few others had, would be "pretty useful" [2E].

The teacher in scenario 2 also felt this was an important element of the Sonic Pi work:

> "… and just the sheer physical learning experience there of physically setting up a machine I thought was a very valuable experience in and of itself and helped to contextualise in a concrete way the ideas about what is a screen, where does that fit in, what am I plugging in here, where are the input devices, where are the output devices and so the theory box of this is a computer made a lot more sense to them because they could visibly see these are the components because I've physically stuck the components in" [KT1].

The physicality of the RPi broadened the conceptualisation of what competence in Computing entails for pupils, most of whom had only used black boxed technology prior to the RPi project, with the exception of the two girls who had done electronics works. It focused the attention on use without detracting from the difficulties of coding a solution or artefact that in many instances led to a loss of confidence, suggesting that working with the RPi could concretize notions of computation. However even with the same resources being used in scenario 4, this does not seem to have had a similar effect, instead leading more pupils to be dismissive of the relevance of Computing, but many believing it to be easier than they previously thought.

In the Minecraft Pi activity, pupils got a great sense of achievement and control from blowing up their peers' creations, and there were obvious opportunities to include discussion into the activity that could have highlighted social issues of abstraction in relation to the advantages of computational abstraction. As a boundary object between Computing and maker practices that incorporate competencies at multiple levels of physicality and metadiscourse, the RPi does lend itself to learning designs that can explicitly encourage a developing knowledgeability in this way, but this would perhaps have more impact if issues such as computational abstraction in social context were made explicit, in line with Kozulin's work (see section 3.1.3).

Logo and Boxer were computational languages that pupils learnt in order to express and manipulate scientific and mathematical ideas. Sonic Pi is a computational language that allows pupils to express musical orchestrations, and in this respect most closely aligns with those earlier initiatives. The python coding that Minecraft Pi and Pi in Space required is a computational language for creating any number of solutions to problems, but was not designed as a teaching tool and thus not designed specifically for expression within a particular domain as Logo and Boxer were. But the physical RPi itself is representational of the technology we use everyday in a parallel way to diSessa's explanation that, "Systematic representational systems aid discovery because they convert abstract "intellectual" patterns into spatial visible ones" (2001, p.17). All pupils were at some point in their learning activity told that the RPi microprocessor was the same as the one in the majority of mobile phones, and there were many questions about how one would go about making the RPi do things that their phones could do. The generally less confident perception of how well they understood everyday technology by pupils in scenarios 1, 2 and 3, and the uncertainty over 'use' in the statement that it is more important to be able to use computers in lots of ways than to be able to program them, suggests that using the RPi did concretize this notion of technology for pupils, depending on pedagogy, over three different learning designs.

10.4. Developing thinking - 'Epistemological pluralism' and reflection

I have discussed how the term 'epistemological pluralism' that Papert used has been shown in the literature to be problematic in its operationalization. What Papert was trying to encapsulate was using computational means to develop an awareness of one's own thinking such that one would be able to see computational methods as just one thinking tool of many, to “articulate the working of his own mind and particularly the interaction between himself and reality in the course of learning and thinking” (Papert, 1970, p.3). This applied equally to educators, who he suggested should consider multiple ways in to, learning designs for, formal, abstract principles. Pedagogy for Papert should aim to counter the hegemony of the abstract and the difficulties inherent in what Sfard calls ‘saming’, or the conflation of discursive levels. Papert felt that learning programming could support learning about thinking, but that this was a very different claim to saying programming develops thinking skills (Papert, 2005, p.367). In describing the RPi work in scenario 2 as “down-to-earth” the pupil was echoing Papert’s sentiments that, “By providing a very concrete, down-to-earth model of a particular style of thinking, work with the computer can make it easier to understand that there is such a thing as a "style of thinking"” (Papert, 1980, p.27). The “down-to-earth” nature of the RPi clearly has some value for the learning experience, as discussed above.

It is beyond the scope of this project to consider the development of computational competence, and I have proposed a move away from an individualistic situating of thought to social constructivist theory of learning that doesn’t situate knowledge as an entity held inside the head. I have not then attempted to claim whether the RPi developed what Papert would have called mechanical ways of thinking in order to be cognisant of different thinking tools, although in the next chapter I will suggest that it would be interesting to take this work forward by mapping developing knowledgeability explored through Q methodology, as I have done in this project, against competency tests. This project instead focuses on perspectives, which are implicitly relative to the context, spatially and temporally, and which Brennan and Resnick (2012) showed are crucial to a learning experience in Computing.

This incorporates the importance of the essence of what we mean when we add ‘critical’ to notions of literacy and thinking. Through the discussion of the wider literature, I discussed that Papert’s aims to develop pupils’ thinking about thinking, or meta-cognitive abilities, and developing educators acceptance of pluralistic pedagogies for formal methods, mirrored those in recent digital literacy and critical thinking around processes of reflection, criticality, and beliefs about knowledge. Pedagogy for technical subjects can lead to deterministic views of the world that may work well for the limited scope of technology domains, but Computing is inherently a trans disciplinary subject, where many of the problems that experts are aiming to solve through computational means are social problems. Such deterministic perspectives are not appropriate for these problems, or for the new shape of knowledge, and thus this is of particular concern in relation to those who may take an inward trajectory into the practices of designing and developing our future technology.

But these notions such as reflection and criticality become objectified as individualistic constructs in the research literature, their functionality becomes secondary to their form, and they become removed from context. I discussed the issues raised by Hofer and Pintrich (1997) around research that is focused on epistemic views, where they highlight: the difference between domain specific beliefs and domain specific knowledge beliefs; that epistemic views are not relevant for children because a sophisticated ontology of a subject is needed before epistemology becomes relevant; and that episteme is presented as stemming from individualistic views rather than being socially situated. In schools where pupils are more or less accountable to regimes of competence that relate to peripheral experiences of practice and also to what it means to be a pupil of a particular school at a particular time, domain specific beliefs and domain specific knowledge beliefs are utterly interdependent. Ways of knowing, as their identification with the subject develops within the wider context of their formal learning experiences, are clearly relevant to the school aged children in this project. Epistemological pluralism is then also a problematic term in its objectification, use of which leads to questions being posed in research that situate knowledge itself as an entity.

I have tried in this project to avoid positioning ways of knowing, labelled either as epistemological or ontological, as something that can be placed on a scale of naïve to mature, and as not relevant to children. Children may not yet have had extensive experience of a domain, either theoretically or practically, but they still exist in a "dynamic and varied landscape of practices", and try to develop "a meaningful identity of both competence and knowledgeability" within their landscape. As a subject in its infancy, Computing perhaps more than any other subject supports the view that instruction leads development: high levels of competence can be demonstrated by young children who have taken the subject up as a hobby, Amy Mather being just one such example (see Chapter 1). Thus development is not necessarily age or stage dependent in this domain and it seems whatever the literature means by epistemic beliefs should not be excluded in considering learning Computing at school age.

I suggested that this project would instead frame research questions through the social theory lens, with the construct of knowledgeability, which is situated rather as a process of locating oneself in a landscape of practices. I then explored these questions in such a way as to capture development of the process over time, and thus still explore the essence of what Papert was trying to achieve. 'Knowledge beliefs' from this perspective become ways of knowing that are relative to the regimes of competence within the school environment, which pupils are more or less accountable to and are more or less able to participate in and to negotiate. We saw that as pupils became more doubtful of their competence in the subject, there were different reactions to their views of the subject knowledge domain and to what it means to learn, depending on what their starting perspective had been. The research explored in chapter 3 predominantly suggests that developing criticality and epistemic beliefs is an acquisition which is then irreversible with respect to time, whereas knowledgeability can develop and vary relative to other areas of a landscape over time in ways that could be construed as either positive or negative.

The methodology used themes to explore the positioning of the statements, but as described in the development of the concourse (see chapter 6) the careful development of the statements in Q methodology can bring to light areas where the participants have interpreted the statements in a different way that challenges those themes. As we saw in the data, the Geek perspective showed a more positive view that they could improve how they learn about Computing, but this is in relation to the fact that they had lost some confidence in their competence, so did not necessarily demonstrate what might be called more of a growth mindset. This particular change could also have demonstrated a conflation of learning and academic achievement, especially given these pupils were also less certain that anyone can learn to program: their previous lower positioning of whether they could improve how they learn could have reflected their high level of self efficacy with respect to the subject. With less self-efficacy in the After study, this could simply suggest they feel they could 'do better' in the subject rather than in how they learnt in this subject. For pupils of this age, in our test driven culture, what they see as learning is likely to be often conflated with academic achievement as test scores are a means to make sense of their progress with respect to the regime of competence of the school. The lack of a test around the RPi work denied them that anchor, and this may have contributed to the reduction in confidence.

I discussed in section 3.1.3 Kozulin's work that suggests literacy in any domain needs to be mediated as a thinking tool, that the distinction between scientific and everyday concepts needs to be made explicit in order for pupils to appreciate it, and that this relates to metacognitive notions of reflection also. Zuckerman also suggested reflection needs to be taught and points out that "few adults manifest highly developed reflective abilities" (2003, p.183). This project showed some evidence that the methodology employed, the process of performing two Q sorts and asking the pupils to compare and explain differences between them, did encourage what the literature would refer to as meta-cognition, but would be better positioned as one process of knowledgeability. Many pupils expressed surprise at the changes in their second sort, although not many were able to take the step to articulating a justification for the change. But in the previous chapter I showed that a pupil from scenario 4, when asked why he had felt less confident after using the RPi that he could teach someone how to program said: "Yeah I think I knew … I thought I knew a little bit more than I did I think". This focus on perspectives, theoretically and methodologically, can still draw out aspects of the essence of what is meant by 'meta-cognition', but in its contextual, situational nature, and relative to aspects of perceptions of school and subject competence and practices.

10.5. RPi and a Pedagogy of expressibility

We saw from pupils in scenario 2 that they felt the teacher had used different strategies in the RPi work than with previous Computing topics, such as learning Small Basic. Even by the time scenario 4 took place, the RPi was hardly being used in schools and the novelty factor of the RPi meant that the teachers could present this as a new tool that they would learn about with the class, in a shared learning journey, and not as something they could hope to be an expert in. The teachers from scenarios 1, 2 and 3 explicitly did this and appeared comfortable with that role. The situation of scenarios 1 and 3 lent themselves to this due to the informal nature of the setting, but this aspect of the pedagogy was equally apparent in the formal setting of scenario 2. Agalianos et al. (2001) had suggested using Logo was more effective in contexts where teachers were willing to 'let go' of control in their classrooms, but this was often not the case:

> “The child-centred principles of Logo challenged the self-image of many teachers as professionals, by threatening to take away the primary commodity of superior knowledge, skills and expertise on which they all, to a greater or lesser extent, relied to maintain control in their classrooms”(2010, p.487).

But in the learning scenarios in this project, ‘control’ seems a simplistic explanation for the different approaches that the teachers were taking in each case. All four scenarios were working with pupils that would be considered well behaved, (acknowledging that perception of behaviour is relative to expectations) control of the classroom appeared no less important to any of the four teachers, and none of them had significantly superior knowledge of the RPi, with only one of the four having a strong Computing background (scenario 1). Further, it would be difficult to describe the principles of the RPi as being at all child-centred, although the Sonic Pi activity design perhaps is more so.

Papert’s constructionism extended Piaget’s idea that children build their knowledge structures by adding “the idea that this happens especially felicitously in a context where the learner is consciously engaged in constructing a public entity” (Papert and Harel, 1991, p.1). According to Resnick in the U.S. National Research Council Report (2011, p.13), programming is a “means of expression and an entry point for developing new ways of thinking”, but the learning scenarios around the RPi have suggested the elements of expressibility are broader than simply those offered by the opportunity to create something. Through work with Scratch, where pupils create animations, Brennan and Resnick add the idea of computational perspectives: expressing (ideas) connecting; questioning. Around these pupils show “evolving understandings of themselves, their relationships to others and the technological world around them” (2012, p.10), which I have suggested is encapsulated by knowledgeability.

Based on the exploration of learning with the RPi, I suggest knowledgeability in school level Computing was enhanced not simply where pupils were creating something, as the pupils in scenario 4 were equally aiming to create an original piece of music, but nonetheless the RPi activity had a less positive impact on their position of knowledgeability. Instead it was enhanced where the creative elements of the learning design, in concert with a responsive pedagogy, enabled the expressibility of broader aspects of identity. This is perhaps simpler to achieve in the open-ended nature of the more voluntary learning scenarios. The end objective and separation of the project into elements based on pupils’ existing expertise in scenario 1, enabled pupils to express aspects of their identity, even for the pupil 1D, who would appear to have had an experience of non-participation. But this wasn’t enabled simply by the end objective itself being negotiable or determined by pupils, as is often the case when pupils use tools such as Scratch and are encouraged to make their own creation. The objective in this case was given by the teacher.

In scenario 3, the pupils worked more individually: even when the Minecraft activity was networked, and pupils were accessing each other’s worlds, the code they were creating was done individually. In scenario 2, expressibility was more inherent in the objective pupils were set, in that they were creating an original piece of music. But more than this, they were able to express their understandings of Computing relative to previous work, and to work across groups in ways that enabled them to express their identity as a member of the various peer groups within the class, not just as students of Computing. The conflict between accountability to the regime of competence of formal education and that of being a Y8 or Y9 boy or girl in a particular community of learners was lessened by the teacher and the learning design, rather than exacerbated. In this way the shared experience served as the primary communication resource, such that participants could reference their own competence as relative to their peers, to locate for themselves an experience of what it means to know Computing in their school, and to “start exploring what they know, what they don’t know, what they only half-know, and what they could learn together” (Wenger, 2009, p.5). Expression and expressibility worked together here: the computational means provided by the RPi activities allowed scaffolding and “expressiveness of particular representations for particular ideas” (diSessa, 2008, p243), but at what might be considered a different level of abstraction, the pedagogy facilitated or inhibited expressibility of identity.

Scenario 2 supported Wenger’s view that “expressibility of the full identity of participants, in all their areas of experience and identification, is an important condition for the richness and meaningfulness of the inquiry” (2009, p.5). Even those who were less confident in their computational competence had opportunities for expression of other forms of identification, as in this example described by 2D:

> “What, what [2A] and I did because we’re not very like good at computing in a certain way as programming like [2C] and [Non-participant] were, we, we kind of like personalised it a bit so we changed the background, changed the colour of like of the logo and we made our like own little screensaver for it so when we turned it on we knew that each of us it gave us a bit of like a thing so ‘oh yeah that's our Raspberry Pi’ [2D2].

The objectified knowledge of computational concepts was incorporated into the learning space in such a way that pupils could negotiate its relevance to both their prior experience of Computing, their personal relation to music, and their relationships with each other and the teacher as members of the school community.

Scenario 2 also showed the benefit of making explicit the expressing of ideas in multiple ways. In scenario 4 pupils had done python programming through Code Academy work, but were not asked explicitly to connect the computational ideas explored in this work and that within Sonic Pi, whereas the pupils in scenario 2 who had completed Small Basic work, were explicitly asked to make these connections on a number of occasions. The teacher in scenario 2 connected these ideas about concrete learning and imagination in terms of non-experiential connections when summarizing what he felt about the choice of a music based activity for the RPi:

> “… and then the actual mechanics of learning a language, I think it was really quite pleasant to learn a language where it was sound based rather than all text based or picture based and that group had done a small exercise using Small Basic previously, where they’d done a little

> bit of kind of text based work, and interacted with it with different degrees of kind of comfort, and sound was a much more universal experience, you know cause I think everybody at one level likes listening to music and to just put it all in, in musical form in that way, you know you got them playing everything from … you know you got natural discussions about music itself, you know I was learning to play the piano at the time as well, and you got very natural conversations about how music fits together as well. So the learning was, there was some very real concrete learning in terms of the computing syllabus but I think it worked well in a classroom with kids as well, I think the kids associate well with it and also I think there was the kind of wider experience of learning music and learning the fact that actually when you're programming anything, you're programming something much larger than just a bundle of code or bundle of text you're trying to bring in real life into code and most things can be coded in that sense and I think it got that idea across as well, and that big picture idea, I don't think we set out to deliver that idea but I think it got that big picture idea I think that mattered" [KT1].

The majority of pupils in scenario 1 already had a coding background so the difficult level of coding was not as much of an issue, in fact the challenge spoke to their existing identification with the subject of Computing or the related subject, electronics. The pupils in scenario 2 mostly did not have a strong background or identification with Computing, but the pedagogy of expressibility that enabled them to bring aspects of their identity with respect to being a pupil of this particular school into the learning space meant their views of themselves as good students was not undermined, as it was for pupils of scenario 4.

We saw that Noss was concerned that "we don't try and squeeze this fantastic revolutionary idea into what is a deeply conservative institution, namely schools" (Westminster Education Forum, 2012, and see chapter 1). But this project would suggest that learning design with the RPi can work well within the limits of a classroom and the benefits of using it in a formal setting is the captive audience. Pupils in scenario 2 who did not identify with the subject initially, still benefitted through its use, and one pupil went on to choose the subject of Computing as an option despite being less confident in his competence. The teacher was able to continue Computing work with these pupils and support them through their crisis of confidence after the RPi activities. If pupils without an existing interest were to experience this outside the classroom, there is perhaps less chance they would pursue it further. For those with a strong interest in the subject already, informal situations may be appropriate to develop this further, but focusing on only those with an inward trajectory perpetuates the idea that we should encourage firstly the pupils with an 'aptitude' for Computing. The pupil in scenario 3, who had presumably been interested enough in Computing to choose to take part in the holiday club, had subsequently become dismissive of the subject. Exploring the starting perspectives of these pupils before they used the RPi supports diSessa's words about Logo that the primary consideration is to "… consider the fit of the software with the existing values and activities of the people who are learning it" (2000, p.119), although for "software" I would substitute *learning design*, otherwise this falls back into technocentrism.

The emphasis on the music component of the Sonic Pi activity and the end objective of the Pi in Space scenarios gave both learning designs a meaningful connection with respect to wider landscapes. In scenarios 3 and 4, where pupils didn't already have an identification with the subject that supported these connections, and where they weren't explicitly encouraged to consider them, we can see at work Wenger's explanation that a boundary practice, such as education, only works if they don't become "insulated from the practices they are supposed to connect … One teacher, isolated from other practitioners and immersed in classroom issues, ceases to be representative of anything else; and artifacts gain local meaning that does not point anywhere" (Wenger, 1998, p.115).

In the next chapter I will summarise these discussion points with respect to how learning design for Computing education with the Raspberry Pi has supported growth in knowledgeability and learning citizenship, reflect on the effectiveness of using the social theory lens as an alternative for 'criticality' as appropriate for school level, and discuss the results in terms of the third and final research question, whether the comparison of two Q studies, Before and After the experience of a learning design, has been effective to explore pupils' positions of knowledgeability.

Chapter 11 – Methodological Discussion and Reflections

The question O me so sad recurring. What good amid these O me, O life?
Answer: that life exists and identity. That the powerful play goes on and that you may contribute a verse (Whitman)

Introduction

In this chapter I will revise the initial problems discussed in the first half of the thesis and summarise the discussion in the previous chapter in terms of answering how the social theory constructs of knowledgeability and learning citizenship enable an effective exploration of developing criticality in learning Computing. This suggests the potential implications of the research in terms of how the findings could inform pedagogic practice. I will also discuss the implementation of Q methodology used in this project, as compatible with the social theory framework, in terms of how it supports the exploration of these concepts and in addition, promotes the development of them with pupils. This presents the potential implications of the research methodologically and theoretically. As part of this discussion I will describe the successes of the project, the potential improvements and recommendations for future research.

11.1. Revisiting the problem space and original contribution

Papert identified two problematic areas for the incorporation of computational means for expressing formal, abstract ideas in school settings: lack of epistemological pluralism and technocentrism. Epistemological pluralism had two aspects: teaching children how to be 'epistemologists', how to be aware of their own 'ways of thinking'; and enabling educators to accept different ways to approach pedagogy for formal, abstract ideas. Technocentrism was a focus on computational tools rather than the context in which the tool was to be used, by both educators and researchers exploring the impact of these tools. Logo was a part of the movement that resulted in creation of a subject of computer studies within schools. Over time this became more focused on IT than computation, and recent changes in the curriculum and development of educational tools such as the RPi, could be seen as a backlash against this situation.

But the discourse promoting computational thinking and denigrating digital literacy reinforces what Turkle and Papert termed the hegemony of the formal and abstract in scientific thought. Research suggests that pedagogy for technical subjects leads to a deterministic mindset and lack of criticality, yet I argue that students with an inward trajectory into these practices, who will design and develop future technology, must have a critical understanding of the tools they are using and creating through their competence with what are referred to as the abstraction processes of computation. Therefore pedagogy needs to incorporate both these elements, but the discourse in the research that has underpinned the development of curriculum and teacher CPD is perpetuating the dualisms of concrete and abstract, knowledge and action, thought and skills, and thus side lining notions of criticality.

Papert's constructionism extended Piaget's ideas for a theory of learning that emphasised the creation of a public entity, but based on Piaget's inherently individualistic notion of thought, this framework for talking about learning does not change the conversation in such a way that the dualisms can be overcome. Research on one of Logo's descendants, Scratch, suggests that a broader notion of perspectives is crucial to learning Computing, (Brennan and Resnick, 2012, p.10, as discussed in section 2.6), but acknowledges the difficulties in exploring how these relate to learning with computational tools. In order to overcome these difficulties, I have suggested a theoretical framework for learning based on practice that avoids objectification of processes such as computational and critical thinking, confusing these as internal, individually held entities that are somehow separate from the practices of which they are a part.

In this research project I have suggested using Wenger's social theory of learning which avoids these false dualities, and situates learning itself as a process of becoming, of identification with respect to a landscape of practices, and thus as inherently perspectival and social. I have used Q methodology in such a way as to capture changes in perspective over time and, in itself, to encourage pupils to consider, not necessarily their own 'styles of thinking', but the ways in which their learning is changing their views, and thus who they are, to create an awareness that this work of the self is a dynamic process.

The original contribution to knowledge of this project demonstrates the impact learning designs incorporating RPis can have on the perspectives of school age children towards learning Computing, depending primarily on relations between existing trajectories and the pedagogy within the learning design, as summarised in the following section. Additionally, this research project uses an original implementation of Q methodology for the educational technology context, using a qualitative comparison of before and after studies, a comparative process in which participants are engaged, to explore the development of knowledgeability.

11.2. Potential pedagogical practice implications: Learning design with the RPi for knowledgeability and learning citizenship

Scenario 1 and 3 relate most to the Geek starting perspective, which is to be expected as these pupils were self-selecting into the scenario and therefore predisposed to have an existing interest in Computing: being most likely to have a 'sojourner' perspective in Fenton O'Creevy et al.'s (2015) terms. The RPi activity has helped broaden knowledgeability here, and the main commonalities in the scenarios were the tool, the freedom to choose the approach to the activities, and a heavy focus on using code as a means of controlling external or alternative artefacts. In scenario 2 and 4 for the 'tourists', pupils who do not have a current inward trajectory to the practice but are simply browsing, the pedagogy around the RPi appears to have determined the experience of knowledgeability. Where there was a pedagogy of expressibility, the pupils developed a broader perspective of the subject domain and consequently more awareness of their own competence relative to this, but not in such a way that their self-subjectification as ‘good students’ was undermined. Where there was a pedagogy driven more by the regime of competence of the school, in this Computing context, the pupils’ identity as a good student was undermined in most cases, and the most shared perspective was dismissive of the subject of Computing despite having more confidence in their ability than other pupils.

Wenger-Trayner and Wenger-Trayner (2015, p.25) tell us “To be fully realized, knowledgeability in a landscape requires that accountability to one location be expressible in another”, and that their own experience of crossing the boundary between academia and consulting is made complicated as, “knowledgeability that we derive from walking that boundary is not expressible in all contexts” (ibid, p.25). One of the questions they ask for knowledgeability is: “What level of identification is associated with inexpressible regions of knowledgeability, with what consequences for one’s experience of participation?” (ibid, p.25). Where the knowledgeability that pupils derive from walking the boundary of being both a pupil of a Computing and of all their other subjects and outside interests was inexpressible in the classroom, and where pupils had a high level of identification with these regions of knowledgeability, then the consequences for their experience of participation was that they became dismissive of that discipline, according to the changes in perspective demonstrated by the Q sorts in this study.

Where pupils had an existing identification with the subject of Computing, the learning design with a RPi that they experienced had a similar effect for all but one participant who had chosen his options during that time. Although he identified with the subject, he did not have an imagined inward trajectory, and did not see a connection between the practice of medicine which he envisaged working towards entering and Computing. Where the learning design did have a similar effect on pupils sharing the same perspective, this was to position the pupils’ perception of their own competence as less positive in relation to the regime of competence of Computing, as they had a deeper perception of what this competence entailed. Additionally they saw more connection between Computing and other areas of school learning, and while still having a somewhat negative view of their own perceived competence in group working, they were more positive about group working and helping others generally, suggesting their position of learning citizenship had expanded. Those with an existing identification in most cases had a parent or close family member who worked in the IT industry.

Where the learning design had a more positive effect on those who did not have an existing identification with the subject before using the RPi, the curriculum of practice was negotiable in ways that allowed pupils to express not only their creative ideas and competence with respect to Computing, but also their competence from other aspects of their school life, both relating to subject competence, and to their identity as a member of that school community. This wasn’t simply down to a learning objective that entailed creating an entity of personal choice, as constructionism and notions of personalised learning would suggest, neither was it simply choice in how to go about achieving a given objective, as notions of learning styles might suggest. Both of these would imply static, subjectifying ideas about the ‘type’ of learner one is. Instead pupils were allowed to express their identity and their becoming relative to the practices within which their location acts as a nexus, and thus opportunities to invest that unique location into the learning space were facilitated by the agile, responsive pedagogy, which includes the environment. This investment of one’s unique location as a learning resource is how we saw earlier Wenger defines learning citizenship. Additionally, pupils’ understandings of themselves with respect to being a school pupil in their context were not undermined for those whose knowledgeability expanded.

The novelty of the RPi as a tool in itself supported this pedagogy, where teachers were able to introduce the RPi as a tool that they were not expected to have expertise in, but this was overridden where the contextual circumstances made classroom management more problematic for the teacher. The learning space relative to the class size, and consequent numbers of RPi kits, had an impact on how collaborative work was enabled: where movement was freer, the collaboration, and associated opportunities for expression, involved more pupils within the collaborations. This pedagogy of expressibility, where expression was not simply a literacy construct of expressing scientific ideas computationally, but rather the expression of identity with respect to subject competence and broader identification in the educational context, reinforces Voloshinov’s definition quoted earlier:

> “The expression of an experience may be realized or it may be held back, inhibited. In the latter case the experience is inhibited expression … Realized expression, in its turn, exerts a powerful, reverse influence on experience: it begins to tie inner life together, giving it more definite and lasting expression” (1973, p.90).

Pupils defined their own competence in relative terms, both for Computing, and being a school pupil: with respect to their perception of the regime of competence of Computing and being a pupil of Computing in their context; but also with respect to their perception of what their peers within the classroom were achieving in the RPi lessons and their perception of peers who were not doing the RPi work. Views about processes of learning and knowledge within the subject domain were relative to each other, to perception of their peers, and to the pupils’ perception of the regime of competence, where a broader perception of what that regime entailed led to more doubt about a universal ability to be accountable to that regime. But this was not simply because pupils had a more ‘deterministic mindset’ and believed learning Computing was only for those with aptitude. As the Geek pupil in scenario 4 explained in the After study, she now saw whether anyone could learn to program as dependent on motivation, having worked in a group where most became dismissive of Computing:

> “Yeah because it depends whether you want to because if you apply if you don’t apply yourself then you're not going to learn and all depends on if you want to or not” [4A2].

The physicality of the RPi was appreciated by the majority of students and was a factor in disrupting their view of their own knowledge with respect to everyday technology, and to the nature of the subject. Learning computation with the RPi can concretise the notion of technology, with respect to what the practice of Computing, and thus the practice of developing and creating new technologies, entails. Pupils whose experience of technology has been predominantly, if not entirely, black boxed have broader conceptions of what controlling technology involves after working with the RPi, even where they have generally negative feelings about the subject. It also concretised general notions of computation, showing a shift in focus for pupils who had only previously done work on screens with software towards use and the practical potential for Computing.

Work with the RPi through any of the four learning designs did not appear to make pupils talk explicitly about their thinking, however the process of doing a Q sort comparison did do this in at least one case. Both elements of reflexivity and ‘concretising abstraction’ could have been made more explicit quite simply within the four learning designs in question and, as suggested in the section below, this would be interesting to explore further.

11.3. Potential theoretical and methodological implications: Q for exploring learning design in terms of knowledgeability and citizenship

Using Q in the temporal and reflective sense used in this project demonstrated changes in perspective with respect to a landscape of practice and participants’ perception of their location in it, over a time period that involved a learning activity that was connected to a subject domain competency for that landscape. It enabled the exploration of perspectives at shared and individual levels, and comparing the results of the two Q studies across these multiple levels, against contextual data, enabled an exploration of what elements of learning design might be important in relation to these changes in perspective.

The theoretical framework led to the situating of learning as becoming, pupils’ perceived and changing location within a landscape of Computing education. The development of the statement set followed standard Q methodology of drawing on existing discourse and representing the communicability of this location. The combination of this methodology with a social theory framework avoided a narrow or evidential list of what might constitute ‘better’ knowledgeability, and thus avoided operationalizing it as simply a list of skills, in the way that criticality has tended to become applied in the literature. Developing knowledgeability is instead a shifting of location relative to various themes and negotiated meaning of statements and, importantly, as relative to perception of the practice one is learning about and the peers one is experiencing the process with. There is thus no ‘right’ position for the statements to be in, no expectations or judgement on what the movement ‘ought to’ be, simply a retrospective interpretation of what the movement has been. Above all, this circumvents the difficulties of pupils learning to ‘play the game’ and give what they believe are the required answers, in an exercise that they might habitually perceive as a ‘test’. Everything expressed in language, that is responsible for what we consider to be real, is relative to perspective at a particular time, and Q draws this out in a way that supports a theory of learning as a social becoming: an individual’s learning is relative to the position of their earlier self; individual learning in one subject domain is relative to that in other domains; and an individual’s perception of their own learning is in a collective relation with respect to other learners, and to the subject and to the school regime of competence.

Looking at these changes in knowledgeability only within the subject domain of Computing, it is easy to see that this is happening for all pupils in relation to their broader landscapes and associated trajectories. Had equivalent Q sorts been performed within other subjects at the same time, they may have shown shifts towards subject level where these Computing sorts have shown shifts away, for example. This is knowledgeability as a dance of the self (Wenger-Trayner and Wenger-Trayner, 2015, p.24), where as accountability to one subject for these tourists increases, it may decrease in another, or increase in several. This method allows exploration of this process relative to a particular programme of study or learning design at a given time, without losing the broader situational aspect of the subject specific perspective. But to use Q sorts as a more embedded formative assessment mechanism across the curriculum with a group of, or all pupils would provide incredibly rich data, especially if pupils also did their own exploration of their set of sorts in a similar, but more practicable way to this study. This relational view that Q provides is also important for analysis and interpretation, for example, pupils experiencing a lack of confidence after facing a difficult topic is not in itself interesting, but relative to other changes, such as perception of the field under study, it becomes more relevant and useful.

There is also some evidence that pupils were supported by the process to take a reflexive approach, even without explicit instruction on how to make the leap to justifying the changes in their sorts. The Q sort comparison showed pupils that identity is dynamic and relative to their learning experiences and if this was embedded into their learning, over considerable time, I believe the methodology could only be beneficial in developing knowledgeability, and what the traditional literature refers to as meta-cognitive skills. The surprise acknowledged by several pupils over their change in views reflects an increased awareness of the fluidity of self. Language, and particularly the process of objectification, may be an agent of continuity but the Q sort comparison made pupils consider their own reinterpretation of a given statement. The statements in this implementation of Q are self-subjectifying to reflect, as the Q set must, statements that pupils make already with respect to their experience in the education system. Sfard's concern that, "As agents of continuity and perpetuation, the reifying and alienating descriptions deprive a person of the sense of agency, restrict her sense of responsibility, and, in effect, exclude and disable just as much as they enable and create" (2008, p.56, and see section 4.3), can be circumvented through comparing Q sorts, as pupils are made aware that their interpretations of a self-subjectified discourse can happen differently at a different time.

11.4. Reflections on the project and future research

In this final section, I will discuss the practical issues of using Q sorts in classroom based contexts, some of the theoretical and methodological issues, general reflections on the overall project, and suggestions for future research over and above those improvements indicated by difficulties faced in this project.

11.4.1. Practical issues for improvement in Q Before/After study comparison

There are some general problems with using Q sorts at school level, and particularly in a timetabled class. When the sorts were done using paper, in scenario 1, there was enough space for pupils to use a large, a3 size card and stick statements directly onto the grid. In scenarios 2 and 3, pupils had an a4 size grid, sorted the statements into piles and then wrote the number of the statement into the grid, as the font would have been unreadable to make the statements small enough to go directly onto the grid. Pupils seemed to manage this with no difficulty, but a more detailed examination of the effect that this extra layer of complexity in the process may have had would be useful.

The online sorts worked well logistically, except where there were a couple of pupils who experienced technical issues on submitting the sort. This was probably due to the number of students simultaneously using the software, and is something that would need to be taken into account if using with larger groups. The problem was resolved by taking a screen grab of the sort, but then the data needed to be entered manually from this image for analysis purposes, so it was not ideal.

In the classroom environment, the teacher in scenario 4 asked pupils to perform the sort quietly, to help ensure it was done individually. However this renders the possibility of doing a Think Aloud Protocol (TAP) during the sort impossible and, particularly in the second sort, this is a really valuable way to get additional data for understanding how the sorter is interpreting the statements. It also appeared to make pupils more reluctant to ask any questions as they were doing the sort, which can highlight contentious statements and is again, useful data.

The reflection process was very difficult for pupils. From the perspective of doing the analysis, it would have been most useful to have some time after pupils have done the second sort to run the analysis and look at the comparison before interviewing pupils, in order to ask questions about items highlighted by the analysis. But this would have lost the immediacy of the sort, and understanding how the pupils have interpreted the statements at that particular time is crucial. Ideally, the second sort would be done with TAP, and then the reflective comparison could be done perhaps one day later. Or alternatively, so that the reflexive process could be embedded into day to day learning, pupils would be set the reflective element as part of the work they do, perhaps making video diaries of their reflections, and would come to understand that they were going to need to justify the comparison of their sorts over every half term. This would perhaps make them more aware of their reasoning as they performed the sort, and in addition would allow more time to do the comparison and think about what factors had played a part in any changes.

11.4.2. Other issues with the Q study Before/After comparison

The development of the concourse and Q sample selection was the most crucial aspect of this research project. Without a set of statements that were appropriate for the age group using them, in terms equally of accessibility and relevance, the data would have been useless. But additionally, the sample needed to work in such a way that the relational connections between statements worked both in capturing aspects of how they were being interpreted and would give insights on comparing relative movements. The Q sample achieved this but there were still improvements that could have been made, particularly for the comparative aspect of the analysis.

One particular difficulty arose through the time-pressured aspect of the second sorts and interviews, where pupils were taking time out of their classes to speak with me. Even in scenario 4, where the online sort had already been completed as part of the class work, the time it takes to look over both sorts and highlight statements that have moved is considerable, and then the reflection is subsequent to this. When pupils were comparing their sorts, the wording of some of the statements was problematic for them in discussing whether the statement had moved more negatively or more positively. For example, the statement “I think being able to use computers in lots of ways is more important than being able to program them” may have moved down in the After sort, implying that they now felt less sure that being able to use computers in lots of ways was more important, and by inference, that they now felt perhaps being able to program them was more important. But the mix of positive and negative relations within the one statement, meant that although a pupil had no trouble interpreting the statement in isolation, and no difficulty in seeing that “number 27 statement has gone down”, they found the wording confusing when interpreting the change between sorts, and started trying to explain why they now felt programming was not so important. “I think computer science is really hard” was another statement that caused some difficulty in the comparison: where the statement moved negatively, the implication was actually that they found the subject to be easier than they previously thought, so a negative movement in position indicated what they saw as a positive outcome and this needed clarifying in the interview on a number of occasions. There were also simple errors when the pupils had both Before and After sorts on equivalent sheets of paper and the sorts weren’t clearly marked, where they confused which was which. Guiding the pupils very clearly through the comparison was crucial.

Another specific issue with the concourse was with statement 21, which did not cause difficulties in the pilot study, but which I feel would definitely need re-wording for future use. The statement is: “I think people who are into computers are seen as geeky” but several pupils, even in the sorts where they were discussing their interpretations as they performed the sort, struggled to apply this statement to their view of how *others* perceive pupils who are interested in Computing, and instead simply referred to their *own* perception of those who are interested in Computing.

The varying levels also made analysis and interpretation more difficult. Firstly, the interpreted nature of statements by each sorter is a strength of Q, but the additional data around the sorts was even more crucial in this qualitatively comparative implementation, when making statements about relative movements of statements, and in considering my own theming of the statements. For example, one pupil may interpret a statement such as “I think my friends or others in my group learn from me as much as I learn from them” very much in the context of Computing rather than in relation to their identity as a school pupil for the first sort, but not in the second. Based on the supporting data, I themed this statement as relevant to their accountability to the school regime of competence, rather than being subject specific. But in analysis and interpretation, in making claims about movements of themes, I had to consider whether each pupil individually was interpreting the statements within that theme at the level at which I had categorised them, and whether that changed between sorts, and where discussing shared perspective comparison, whether that was the case for all the pupils loading on that shared perspective.

Another issue in the comparison, both for the pupil interview and in the overall interpretation was deciding what level of change was worthy of consideration. Due to the time pressure, in interviews pupils were asked to note those statements that had moved more than two columns. In comparing the studies, all movement was considered. This was done because, although a considerable change in position of an individual statement is interesting in itself, the sort is intended to represent an entire perspective, and so it is always the position of a statement as relative to the others that is central. The limitations of a nine column grid have been mentioned earlier in terms of interpreting different factors, and this was equally the case for comparing movement. Sometimes statements might move three columns and yet still be on the same side of the grid, so remain positive for example, and a statement that moved only two columns but shifts from positive to negative may be of more interest, depending on how it had moved relative to other statements. Here again, the additional data from interviews was crucial in the interpretation, and this is where more time to support the pupils in the reflection process, or even better, repeating the process multiple times as a learning experience, would have supported this analytical process further.

11.4.3. General considerations

As the RPi was new when this project began, there was a very limited number of scenarios in formal education to explore, and as described, two of the scenarios in this project were voluntary based, while two were enforced. This was advantageous in comparing contexts with very different pedagogy, and in comparing use of the Sonic Pi resources in situ with both enforced scenarios. It would be useful however to do further comparisons in both informal and formal settings, to explore more how far the impact on pedagogy with the RPi was driven by the formality of the setting.

There were also different numbers in each scenario, which could be considered problematic. However the comparisons were between Before and After studies: the context was used to consider aspects of design that may have affected differences in the studies, but the contexts were not compared in any quantitative way. But as above, further study comparisons between more similar contexts with greater numbers could possibly provide finer detail.

This project was made more difficult by the nature of the setting and the technology. Working with schools who were adopting a brand new technology meant working with teachers who did not necessarily already have an existing relationship with the University, or who had no experience of research projects. This led to a very time consuming amount of project management over the course of the study, particularly when two teachers began, but were unable to complete, their work for the study. Additionally the technology of the RPi and the resources around it changed significantly over the timeframe of the project, and participant teachers needed support with managing the technology, more so where their own IT support staff were unable to get involved.

11.4.4. Recommendations for future research – new questions

In addition to the improvements that could be made to this study, there are a number of extensions that could support confirmation of the ideas that emerged through the analysis and further questions that the findings raise that would be interesting to explore. In the former case, it would be interesting to explore pedagogy that enables expressibility, using alternative methods to define more clearly whether this has an impact more widely than in Computing classes, how this works at school level and thus how teachers can be supported to approach this. It would be beneficial also to explore more examples of the RPi in learning design where the physical board is more integral to the activity, such as in the PiFace activity, which was used less in this study than any other activity, but is where the RPi most strongly situated as a connection between the practical and metadiscursive levels of activity. This would be of particular interest at the moment given the BBC Micro project (see http://microbit.org/), which has provided a simpler low cost board, the BBC Microbit, to every Y7 pupil in the UK to do Computing projects based on ideas around wearable technology.

As mentioned above, while the focus of this project is knowledgeability, and using Q methodology study comparison to explore this, it would be very interesting to explore how it might be possible to develop Q sorts that represent specific competencies, as informed by social learning theory rather than as a set of skills or 'knowledge' that can be evidenced through regurgitation onto paper or screen, and to use these in conjunction with Q sorts for knowledgeability. More easily achievable perhaps would be to use existing competency tests in Computing such as the Bebras tests, and use these in parallel with Q study comparisons. This would enable a more in depth consideration of knowledgeability with respect to competence. Ramlo (2008) has done similar work in exploring notions of learning episteme and conceptual understanding of physics, but as I have shown in this thesis, learning episteme is a problematic construct and additionally, Ramlo only uses post competency and learning tests, rather than a Before/After model.

It will be useful as the RPi and new technology such as the BBC Micro develop and research evolves around them, to explore whether the discourses promoted by the frameworks used continue to perpetuate technocentrism and the hegemony of the abstract, or whether the research community can be persuaded by work such as that inspired by the ScratchEd team, to move away from individualistic notions of learning perhaps through using methods such as Q methodology.

11.5. Final note

The debate over whether all children should learn to code or whether it is only relevant to those entering a computing practice is not likely to be resolved soon, neither is whether coding is simply a tool or part of an entirely new literacy, or agreement on a definition of computational thinking. But in the meantime, as Mitchell suggested in 1980, now Computing teachers as well as HE level academics are “the stewards of all that is known about the use of this machine” and so ensuring a critical approach is taken in learning all elements of the subject has to be part of their responsibility, as well as the computational elements of competence. Papert said:

> “People often ask whether in the future children will program computers or become absorbed in pre-programmed activities. The answer must be that some children will do the one, some the other, some both and some neither. But which children, and most importantly, which social classes of children, will fall into each category will be influenced by the kind of computer activities and the kind of environments created around them” (Papert, 1980, pp.29-30)

The formal school environment may not be conducive to innovative educational technologies, but until technology can disrupt the education system drastically enough to lead to Papert’s dreamed of revolution, I would argue, based on my experience of this project, that the conservatism of the system can be circumvented in local contexts to ensure it isn’t only those pupils who are predisposed to the industry who benefit most from these innovations. Additionally, the captive audience of a classroom can provide an ongoing supportive environment to move past early challenges of the competency development in the subject, but this can be done more effectively when competence isn’t the only measure of achievement and the only measure informing learning design.

I believe diSessa is right in explaining science as “… an articulate re-experiencing of our own reality in a different form. It is supported by technical representations such as algebra and concepts that are simply *not* the common sense either of everyday experience or even of an alternate holodeck reality” (2008, p.112) but it doesn’t take place and isn’t studied in isolation from practice or from the identity of those who practice science or are in the practice of studying it. Both expression and expressibility, conceptual representation and representation of self, need to be incorporated into pedagogy.

I found Q study comparison to be an ethical way to explore learning, situated as a social becoming, in that it includes all voices, inherently asks learners to be reflective, and perhaps most importantly it emphasises participants’ own meanings and understandings rather than those of the researcher. This methodology led to results that I was not expecting, even after having observed the participants during their learning activities. Implementing this methodology with an additional temporal aspect was compatible with the social theory of learning of which the construct being explored, knowledgeability was a part, and on which themes for analysis were based. The methodology and the theory take a dynamic, locational or perspectival approach, despite the theory being one of practice and the methodology being predominantly discursive.

Based on the learning from this project, I believe learning design around the RPi does have the potential to support developing knowledgeability and despite being touted as a tool to teach computational thinking, its strength is that, with the right supporting pedagogy, learning design around it can expand what Brennan and Resnick (2012) call computational perspectives. Through the methodology used in this project, we can explore learners' shifts in understanding of themselves and the world through computational activities. This is only possible by moving the discourse away from the hegemony of the formal and abstract, such as the SDR abstract divisions of the subject into a false hierarchy, and Wenger's social learning theory accommodates this move. In this project pupils can be seen to be constructing their identities in a holistic way across all aspects of the subject, as they explore computational competencies, which range from entirely abstract symbol manipulation, to creating sound and physically manipulating control devices.

The use of the RPI in learning Computing brings a physicality to the experience that even in small ways, undermines the hegemony of the abstract. This appears to encourage a positive growth in knowledgeability, even if only to provide a broader view of the subject by concretising the idea of CS as a subject, the competencies of which are no less practical than they are conceptual, should such a distinction be made, although the priority for adopting a construct of knowledgeability is an attempt to move away from these discursive divisions. This support for knowledgeability appears most effective when the pedagogical design facilitates pupils in expressing their identities and not just their computational understanding or creative intentions.

Constructs of knowledgeability and learning citizenship avoid operationalizing the essence of what is meant by criticality in a teleological way. These terms avoid dualities of abstract and concrete and so cannot privilege one over the other, and allow for instruction to lead development without assuming that development is unidirectional: knowledgeability is an evolving location not an end point, and moving from an exploration of criticality to one of knowledgeability prevents the researcher or educator from looking for an impossible 'end' and speaks to Dewey's temporal ethics where he claims, "Til men give up the search for a general formula of progress they will not know where to look to find it" (Dewey, 1922:1983, p.196).

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Appendix A - Communities of Practice Core Constructs

1. Practice

Wenger describes a number of social theories in order to situate the Communities of Practice (CoP) theory, and makes clear that he uses the term practice "… in the sense of a competence derived from a collective learning process that creates continuity across time and space, as in the expression 'medical practice'" (Wenger-Trayner, 2013, p.113-114). Similarly, "The notion of community of practice, for instance, is not true or false. It is a way of thinking about the social nature of the negotiation of competence" (ibid, p.106). He operationalizes practice as: meaning; community; learning; boundary; and locality.

2. Meaning

Meaning in CoP theory is not meaning as Voloshinov (1973) defined it, as tied to particular words, but more closely aligns with the latter's notion of theme, in that it is defined in terms of practice: "*Practice is about meaning as an experience of everyday life*" (1998, p.52). Meaning resides in the process of negotiation of meaning, which involves participation and reification. Participation is "the social experience of living in the world in terms of membership in social communities and active involvement in social enterprises". (ibid, p.55). This can be a conflictual as well as harmonious process, and it works dialectically, as participation in social communities both shapes our experience, and allows us to shape the practice of our communities. It doesn't end with immediate practice, but becomes part of our identity that is carried with us, and is therefore "constituent of our identities" (ibid, p.57).

Reification is defined in a very similar way to Sfard's objectification but does not refer solely to discourse, but also to tangible objects or tools: it is "the process of giving form to experience by producing objects that congeal this experience into "thingness". In doing so we create points of focus around which the negotiation of meaning becomes organized" (ibid, p.58). Examples Wenger gives of such reification include medical claim forms, names, the Constitution, advertisements, concepts and theories. We can see the development process and branding around the RPi tool and the emergence of maker faires as reifying experience, and of course curriculum is very much a reified object. This process in turn shapes experience through the reified tools, in a way that aligns very closely with much of how the literacy literature describes the influence of mediums of literacy. The mediums which have become reified embody and in turn influence the practices in or for which they were created, such as the example Wenger gives of a word processor that "reifies a view of the activity of writing, but also changes how one goes about writing" (ibid, p59). Like objectification, reification can be helpful and problematic, and can "give differences and similarities a concreteness they do not actually possess" (ibid, p.61). This duality of participation and reification in constituting the negotiation of meaning allows us to look at how meaning is distributed, "what is reified and what is left to participation" (ibid, p.64) and he gives the contrasting examples of a computer program, which "could be described as an extreme kind of reification, which can be interpreted by a machine incapable of any participation in its meaning" and a poem, which "is designed to rely on participation, that is, to maximize the work that the ambiguity inherent in its form can do in the negotiation of meaning" (ibid, p.64).

3. Community

Wenger applies three dimensions to distinguish the general notion of community from a CoP. These dimensions are mutual engagement, shared repertoire and joint enterprise. Mutual engagement is what defines a community, rather than just a network, team or group. "Practice resides in a community of people and the relations of mutual engagement by which they can do whatever they do" (ibid, p.73) and the community negotiates meaning around this engagement. Engagement defines belonging (ibid, p.73-75). A joint enterprise is defined in the "process of pursuing it" (ibid, p.77) and is a negotiated goal that creates "relations of mutual accountability" among participants (ibid, p.78). It is the negotiation that makes it "joint" rather than inferring straightforward agreement. A shared repertoire is the "resources for negotiating meaning" such as language, code, procedures, words, stories, gestures, and, in the case of this study, the RPi, which "gain their coherence not in and of themselves as specific activities, symbols or artifacts, but from the fact that they belong to the practice of a community pursuing an enterprise" (ibid, p.82). The repertoire reflects history but is still ambiguous:

> "When combined with history, ambiguity is not an absence or a lack of meaning. Rather it is a condition of negotiability and thus a condition for the very possibility of meaning" (ibid, p.83).

Formal education is itself a practice: arguably the foremost objective of this practice is that of preparing young people for future practices such as Computing. In a school setting there may be many communities of practice but a classroom is rarely one: before KS4, the pupils are unlikely to be in a Computing lesson out of choice, and thus the joint enterprises in the room on any temporal level, over an academic year or momentarily, may range from getting through the school day, to getting good grades, to learning how to create a mobile app. Simplistically, there may be a group of pupils who join an after school coding club, from which a community of practice emerges as the pupils mutually engage in the club sessions and perhaps at home, communicating, between face-to-face sessions, about learning to code. They may all be learning an element of the practice of Computing, around a system on chip computer such as the RPi, through a project that solves a need within their school community, which the group identify and negotiate themselves, rather than being given a directive from a teacher. Even in this scenario it is not straightforward to say whether this group could indubitably be called a CoP, largely because of issues of boundary, which are introduced in the main text, chapter 5.

4. Learning

Wenger talks about learning both as a characteristic of practice, as situated in this part of the theory, and individually as a process of identity, which we will come to in the next section. In terms of practice, CoPs can be thought of as "shared histories of learning" (p.86). Participation and reificiation is again a key duality here. Reification produces persistent forms that act as a source of remembering and forgetting, and similarly participation through our memories, interpretation of memories and related identity building processes. The interaction of these processes of participation and reification connects us to our histories, and provides continuity and discontinuity. As such the processes offer "two distinct channels of power available to participants" (ibid, p.91). The continuity and discontinuity create a "dynamic equilibrium that can be construed, by participants and by the encompassing institution, as stable and as the same practice" (ibid, p.95).

As a social history of learning, a CoP is an emergent structure with no definitive beginning and end, with life cycles that reflect the fact that "Learning is the engine of practice and practice is the history of that learning" (ibid, p.96). Membership of CoPs is dynamic: there are newcomers and old timers in CoP's, and people become part of and retract from CoPs in various degrees over time (p.99). Peripherality and legitimacy are important terms here in relation to Lave and Wenger's 1991 work on apprentices, where peripherality is an "approximation of full participation that gives exposure to actual practice" (ibid, p.100) and where granting newcomers enough legitimacy to be treated as potential members is important.

5. Identity

Identity and practice are presented as "mirror images of each other" (ibid, p.149) and practice involves "ways of being a person in that context" (ibid, p.149). Identity as a concept:

> "… serves as a pivot between the social and the individual, so that each can be talked about in terms of the other. It avoids a simplistic individual-social dichotomy without doing away with the distinction. The resulting perspective is neither individualistic nor abstractly institutional or societal. It does justice to the lived experience of identity while recognizing its social character – it is the social, the cultural, the historical with a human face … It is therefore a mistaken dichotomy to wonder whether the unit of analysis of identity should be the community or the person. The focus must be on the process of their mutual constitution … in a duality it is the interplay that matters most, not the ability to classify" (ibid, p.145-146).

Wenger explains that the individual/community separations are simply reifications that loose the interconnectedness and the complexity of society (ibid, p.146). In the CoP theory there are no underlying assumptions of good or bad, conflictual or harmonious in the notions of individual and social. Identity in CoP acknowledges the discursive, narrative aspects of identity, but positions these also as reifications, and Wenger extends the notion to include:

> "… the way we live day to day, not just in what we think or say about ourselves, though that is of course part (but only part) of the way we live. Nor does identity consist solely of what others think or say about us, though that too is part of the way we live. Identity in practice is defined socially not merely because it is reified in a social discourse of the self and of social categories, but also because it is produced as a lived experience of participation in specific communities… An identity, then, is a layering of events of participation and reification by

which our experience and its social interpretation inform each other. As we encounter our effects on the world and develop our relations with others, these layers build upon each other to produce our identity as a very complex interweaving of participative experience and reificative projections. Bringing the two together through the negotiation of meaning, we construct who we are. In the same way that meaning exists in its negotiation, identity exists – not as an object in and of itself – but in the constant work of negotiating the self" (ibid, p.151).

Competence is integral to the idea of community membership. As full members of a community, we experience being and are recognised as competent members of that community. The dimensions of competence for a community described above, can thus be related directly to identity: mutuality of engagement, where "we become who we are by being able to play a part in the relations of engagement that constitute our community" (ibid, p.152); accountability to an enterprise, where our participation in enterprises leads us to adopt perspectives that take into account what we consider relevant to those enterprises; and negotiability of a repertoire, where we can make use of the shared history of a practice "because we have been a part of it and it is now a part of us" (ibid, p.153).

As an identity is ongoing work of negotiating self, it has a motion and "a coherence through time that connects the past, the present, and the future" (ibid, p.154). Wenger suggests this motion, which he calls trajectories, can remain at the edges of a practice (peripheral trajectories); can be leading towards full participation in a practice (inbound trajectories); can occur within a practice as that practice evolves (insider trajectories); can span across CoP boundaries (boundary trajectories); and can lead out of communities (outbound trajectories). For school pupils of Computing, the potential trajectories supported by the pedagogies they encounter are hopefully peripheral to practices within subject domains, with the possibility in the later stages of schooling for inbound trajectories, as pupils begin to narrow their choices. Of course outbound trajectories are a focus at this time also, leading out of the CoPs in which children have participated through their formal schooling, and "What matters then is how a form of participation enables what comes next … being on the way out of such a community also involves developing new relationships, finding a different position with respect to a community, and seeing the world and oneself in new ways" (ibid, p.155).

Identity is a matter of both participation and non participation: "In practice, we know who we are by what is familiar, understandable, usable, negotiable; we know who we are not by what is foreign, opaque, unwieldy, unproductive" (ibid, p.153). We make decisions about what is important, what to be accountable to, and what is not significant, however the latter does still form part of who we are as do all our encounters. The interaction of participation and non participation Wenger describes as peripherality, and marginality. In the former, a less than full membership is enabled and supported, an authentic but peripheral engagement, and non participation is thus an enabling factor of participation. With marginality, the "non-participation prevents full participation" (p.166). The difference between these is subtle but leads to very different experiences. If we take an example of a group in an after school club working on RPi projects, peripherality would enable a pupil new to the group to work on tasks that were perhaps more straightforward but still integral to the overall project, or to work in a pair with a more experienced member of the group, allowing the newcomer to get involved with the group quickly without necessarily having the same level of competence. But if the coding competence the pupil had achieved was not at a level where the tasks set were achievable even with peer support, or if the experienced peer simply took over coding tasks without involving the newcomer, the experience could very easily be one of marginality, depending on how the newcomer negotiated this experience as part of their identity trajectory.

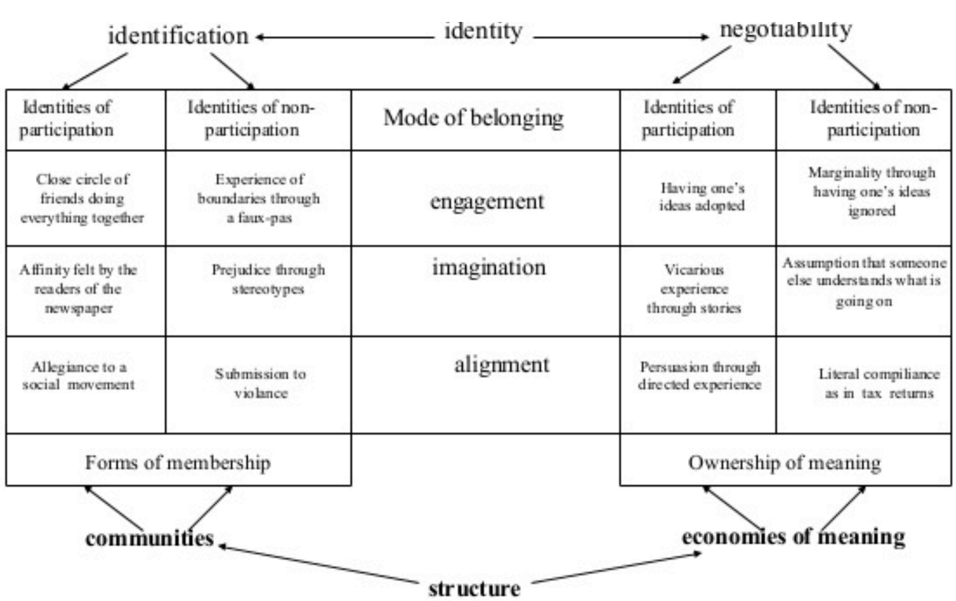
Learning then is a process of identity. Trajectories “give significance to events in relation to time construed as an extension of the self. They provide a context in which to determine what, among all the things that are potentially significant, actually becomes significant learning” (ibid, p.155). A CoP offers paradigmatic trajectories in the form of those experienced by old-timers who have been part of shaping the history of the practice. A CoP is then a “field of possible trajectories and thus the proposal of an identity” (ibid, p.156). This interaction between old-timers and newcomers leads to a negotiation of trajectories, which is “always a complex meeting of the past and future, one in which generations attempt to define their identities by investing then in different moments of the history of a practice” (ibid, p.158).

A nexus of multimembership refers to the fact that we engage in multiple practices, to varying degrees and varying over time, and as such, an identity is not just a singe trajectory and is “not a unity but neither is it simply fragmented … In a nexus, multiple trajectories become part of each other, whether they clash or reinforce each other. They are, at the same time, one and multiple” (ibid, p.159). As learners move across different CoPs, they have to reconcile aspects of competence, work which is never complete and “entails finding ways to make our various forms of membership coexist” (ibid, p.160) work that is “at the core of what it means to be a person” (ibid, p.161). Agency is here, in the creative nature of reconciliation work, which has the potential to rearrange relations within our CoPs. It is thus a “profoundly social kind of work” but also very personal, as “By incorporating into the definition of the person the diversity of the social world, the social notion of a nexus of multimembership thus introduces into the concept of identity a deeply personal dimension of individuality” (ibid, p.161).

In addition to engagement in practice, imagination and alignment are also modes of identification with practices. Engagement is bounded, in that there are limits to what we can do, for how long and in what locations. Imagination is an important part of our experience and identity work, and does not relate purely to imagination in the sense of creativity or fiction, but to the ability to connect with experiences distant from us in time and space. It includes Dewey’s dramatic rehearsal, the deliberative “experiment in finding out what the various lines of possible action are really like” (Dewey, 1983, p132). This is a very powerful part of experience as “We continue to react to an object presented in imagination as we react to objects presented in observation.” (ibid, p.139). To demonstrate the power of imagination in learning, Wenger gives the example of two stonecutters who each describe their task differently, one claiming they are cutting stone into a square and one that they are building a cathedral: “The difference is a function of imagination. As a result, they may be learning very different things from the same activity” (Wenger, 1998, p.176). Imagination allows us to “recognize our own experience as reflecting broader patterns, connections and configurations" (ibid, p.178) but can also be based on stereotypes and be "so far removed from any lived form of membership that it detaches our identity and leaves us in a state of uprootedness" (ibid, p.178). Alignment allows us to connect to larger enterprises and coordinate efforts across space and time, such as through aligning to the requirements of the organisations we work for, and is concerned with power "over one's own energy to exercise alignment and the power to inspire or demand alignment" (ibid, p.180). It enables us to manage complexity in ways that "give new dimensions to our belonging" (ibid, p.180).

In terms of participation: engagement requires that participants can engage with each other and contribute to the enterprise; imagination requires time and motivation to try new ideas and identities, exposure to new ways of doing things; and alignment requires boundary practices and people who can coordinate perspectives across boundaries. In terms of reification: in engagement, participants require access to the reified objects of the practice; imagination requires material such as visualization tool and stories – "tools to see patterns in time and space that are not perceivable through local engagement" (ibid, p.186); and alignment requires boundary objects, such as the RPi, around which to coordinate perspectives.

Wenger summarises the identity side of the theory in the diagram below. Seeing identity as an interplay of negotiation and identification positions power as embedded in the negotiation of meaning and formation of identities. Within engagement, identification is a two way process, but a "lack of mutuality in the course of engagement creates relations of marginality that can reach deeply into our identities" (ibid, p.193).



Wenger, 1998. Social ideology of identity

Imagination can both connect and distance us, as we imagine differences and commonalities. This mode of identification becomes important in terms of Wittgensteins 'pictures' - we establish, "a picture of the world into which the self can be projected. Not only is building that picture of the world and locating ourselves in it as much a part of identification as engaging in practice, but the two processes also feed each other. Our practices provide resources for building that picture, and that picture in turn determines how we understand our engagement in practice" (ibid, p.195). Here we see how processes referred to as thought and Freire's notion of criticality for social action can be drawn together. They are both elements of the work of identification, neither hegemonic over the other.

Identification through alignment can allow us to be a part of a larger context, such as allegiance to a sports team or political activism, and as such can be “a very profound aspect of how we define ourselves” (ibid, p.196). It involves compliance and allegiance and as such results in a mix of participation and non participation. In Computing lessons with RPi, we see alignment in terms of the notion of ‘the geeks’, and to ‘the academics’, and compliance in varying degrees to the teacher’s and institutions expectations of compliance.

Negotiability reflects issue of power, as practice produces meanings, some of which may hold more currency than others, and where participants may have more or less ownership of meaning, more or less influence in how meanings are negotiated in the practice. This emphasizes the notion of meaning as defined in use and the notion of digital literacy is a straightforward example of how the term can have very different meanings for literacy academics advocating a critical agenda for education, and a working group of Computing academics and educationalists aligning with a political discourse that advocates an abstract notion of competence for scientific subjects. Teachers have no ownership of meaning of the term within the curriculum, but they can negotiate what it means in their local pedagogic practice (local in terms of their geographic school settings, but also in terms of teachers within the same practice with whom they may work closely through organisations such as CAS). But however ‘well intentioned’ the working group may have been, any negotiation of meaning for teachers is much more difficult now the meaning of digital literacy has been appropriated by the professional Computing community, in the way Wenger describes for other concepts:

> “Ownership of meaning is defined within economies of meaning where the values of meanings are interdependent. Thus appropriation by some can entail alienation from others. For instance, the appropriation by professional communities of such concepts as health and justice is meant to generate practices and artifacts in the service of these public issues. But the technical discourses of such professional communities often end up constituting claims of ownership of the issues themselves. Such claims devalue the nontechnical understanding of these issues by the rest of the population, even though the definitions of issues like health and justice are in the end not primarily technical” (ibid, p.201).

The constructs of CoP focus on processes of practice and identification rather than an individual-collective dichotomy. Further, it focuses on the interplay of these processes, rather than objectifying the processes themselves. Communities form because “identification is at the very core of the social nature of our identities” (ibid, p.212) and these create economies of meaning because negotiability “is at the very core of the social nature of our meanings” (ibid, p.213). The changing shape of knowledge as a result of technological developments, creates “wider, more complex, and more diversified economies of meaning and communities. With respect to the potential for learning communities, issues of identification and negotiability are then heightened, not transcended” (ibid, p.221). Then the notion of knowledgeability, a construct introduced by Wenger in more recent work, becomes a valuable lens, in relation to competence, to explore the learning we have seen the literature suggest is crucial for a world that is too big to know.

Appendix B - Statement development

The table below shows the original statement selection that was trialled in the pilot study, the amended statements and notes regarding why changes were made.

No.	Original	Amended	Comments from pilot
1	I think I am a good programmer	I think I know how to program a computer	Being a programmer implied a level of practice pupils couldn't relate to
2	I think what I learn in my lessons is more important to me than the grades I get	I think what I learn is more important to me than the grades I get	Some pupils referred to learning outside of lessons, which I felt needed to be incorporated
3	I think people who can program computers are more powerful than those who can't	I think people who can program computers are more powerful than those who can't	Unchanged – although interviews included questioning on how pupils defined 'powerful'
4	I think I could confidently use the technical skills I have right now to build a control device	I think I could build a device that controls something	The level of confidence could be discussed in the interview and was expressed through positioning
5	I think it will be/is clear how this activity is connected to other subjects	I think I can see how what we are learning will be/is relevant to other subjects I study at school	With 'connected' pupils sometimes interpreted this to mean a more tangible connection, such as associated grades
6	I think what I learn/am learning in this activity will gain me respect from peers	I think friends who haven't done this activity would/will be impressed to hear what we are doing	Respect and peers were not words that pupils seemed to relate to
7	I think I could teach somebody else how to program a computer	I think I could teach somebody else how to program a computer	Unchanged
8	I think I will use what I learn/t in the activity in my future career	I think I will use in the future what we are learning	Many pupils dismissed this as they had no idea what their career might be
9	I think Computer Scientists can make the world a better place	I think people who make and program computers can make the world a better place	Pupils were confused by what a Computer Scientist might do and I agreed it isn't a well defined practice outside of academia
10	I think I understand how everyday technology works	I think I understand how the technology I use every day, like my mobile phone, works	Several pupils asked for clarification of the term 'everyday technology'
11	I think the assessments we do are the most important thing	I think doing well in tests and exams is the most important thing in school	Most pupils questioned exactly what was meant by assessments and felt it meant the most important thing in life, so the majority placed this quite negatively
12	I think computer science is about building	I think computer science is about building	Unchanged

	computers	computers	
13	I think I know more about computers than most people my age	I think I know more about computers than most people my age	Unchanged
14	I think I am a valuable team member	I think others think I am good at working in a team	As it became apparent that perception relative to peers was important, I felt asking how they felt others perceived them was more useful and several pupils added comments about this anyway
15	I think computer science is about making software	I think computer science is about making software	Unchanged
16	I think I can improve my ability to learn	I think I can improve how I learn about computing	Nearly all pupils said it depended on what they were learning. However in hindsight I feel including 'ability to' would have been better
17	I think learning about how computers work is really important for my future	I think learning about how computers work is really important for my future	Unchanged
18	I think Computer Science is about problem solving	I think computer science is about solving problems	A small change to put the focus on the process, as pupils seemed to focus on the 'problem' word in isolation
19	I think I will be able to use what I learn/have learnt in other subjects	I think I can improve marks I get in all subjects through learning about computing	'Use' was too vague and reworded to be more specific to school regime and work in concert with statement 5 which is focused on learning but looking for similar connection
20	I think computing is a really hard subject	I think computer science is a really hard subject	At this stage pupils weren't really sure what Computing was, and when asked to define both, they were closer to the new curriculum when they defined computer science
21	I think people who are into computers are seen as geeky	I think people who are into computers are seen as geeky	Unchanged but with the main study, in all scenarios this was problematic for at least one participant
22	I think I have a clear idea of what I want to do after finishing school	I think I have a good idea of what I want to do after I leave school	Slight rewording based on questions on 'clear' and 'finishing'
23	I think if I write a program what is most important is that it works correctly	I think if I write a program what is most important is that it works correctly	Unchanged
24	I think I am a good student	I think I am a good student	Unchanged
25	I think if I write a program what is most important is that it helps somebody	I think if I write a program what is most important is that it helps somebody	Unchanged
26	I think computer science is more of a natural science than a social science – it consists mostly of unarguable facts	I think computer science is like maths and physics more than it is like history, sociology, citizenship	This was just too complex for pupils to unpick within the time frame of the sort and caused hesitation for every pupil in the pilot study
27	I think programming is more important than using	I think being able to use computers in lots of ways	This required clarification from most pupils

	computers	is more important than being able to program them	
28	I think my fellow students do, or would, benefit from working with me	I think my friends or others in my group learn from me as much as I learn from them	There was a lot of ambiguity around ‘benefit’
29	I think that anyone can learn to program	I think that anyone can learn to program	Unchanged
30	I think the best thing about group work is the opportunity to learn from other students	I think when we work in a group we learn from each other	Several pupils suggested they don’t learn from other students, which missed the point of the statement
31	I think that people can learn to program in their spare time without a teacher	I think that people can learn to program in their spare time without a teacher	Unchanged
32	I think I learn more by listening than doing	I think I learn more from the teacher telling me things than from doing the activity	This required clarification from most pupils
33	I think group work is the best way to learn	I think I learn more when I am helping other people to do things	This was one of the statements where most pupils said “It depends…”
34	I think being a good computer scientist means having good people skills	I think being a computer scientist means being good at talking to people	“People skills” required too much clarification

Statement groupings

1 I think I know how to program a computer

7 I think I could teach somebody else how to program a computer

2 I think what I learn is more important to me than the grades I get

11 I think doing well in tests and exams is the most important thing in school

3 I think people who can program computers are more powerful than those who can't

9 I think people who make and program computers can make the world a better place

5 I think I can see how what we are learning will be/is relevant to other subjects I study at school

19 I think I can improve marks I get in all subjects through learning about computing

8 I think I will use in the future what we are learning

17 I think learning about how computers work is really important for my future

12 I think computer science is about building computers

15 I think computer science is about making software

18 I think computer science is about solving problems

14 I think others think I am good at working in a team

16 I think I can improve how I learn about computing

20 I think computer science is a really hard subject

29 I think that anyone can learn to program

23 I think if I write a program what is most important is that it works correctly

25 I think if I write a program what is most important is that it helps somebody

26 I think computer science is like maths and physics more than it is like history, sociology, citizenship

27 I think being able to use computers in lots of ways is more important than being able to program them

28 I think my friends or others in my group learn from me as much as I learn from them

30 I think when we work in a group we learn from each other

33 I think I learn more when I am helping other people to do things

31 I think that people can learn to program in their spare time without a teacher

32 I think I learn more from the teacher telling me things than from doing the activity

Individual

4 I think I could build a device that controls something

34 I think being a computer scientist means being good at talking to people

6 I think friends who haven't done this activity would/will be impressed to hear what we are doing

13 I think I know more about computers than most people my age

24 I think I am a good student

21 I think people who are into computers are seen as geeky

22 I think I have a good idea of what I want to do after I leave school

10 I think I understand how the technology I use every day, like my mobile phone, works

Appendix C – Example participant consent form

Raspberry Pi and Computing Education

Participant Information Sheet

You are being invited to take part in a research study to look at how using Raspberry Pi for learning activities develops critical and computational thinking. Before you decide it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Please ask if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part. Thank you for reading this.

Who will conduct the research?

Amanda Banks Gatenby, School of Education, University of Manchester, M13 9PL.

Title of the Research

Engaging imagination – how can learning design incorporating Raspberry Pi technologies support criticality in Computer Science education?

Why have I been chosen?

Because your teacher is going to do some activities with you using Raspberry Pi.

What would I be asked to do if I took part?

If you decide to take part, you will be asked to take part in two focus group discussions, which means a discussion with the researcher and two or three of your fellow students. One of these will be before the Raspberry Pi activity and one after. Your group would also be observed (the researcher will watch what your group are doing) and audio recorded during the activity.

What happens to the data collected and how is confidentiality maintained?

Digital files and all other data used in the research will be stored in a secured file. Data will be anonymised. This file will be encrypted and stored on a secure server. The file and all other data will be stored until the analysis is complete, and will then be archived for five years. After this time it will be destroyed. This data will be stored and may be accessed in accordance with the Data Protection Act.

What happens if I do not want/my child to take part or if I change my mind?

It is up to you to decide whether or not to take part. If you do decide to take part you will be given this information sheet to keep and be asked to sign a consent form. If you decide to take part you are still free to withdraw at any time without giving a reason and it won't stop you taking part in the activity. Nothing you are doing as part of this study counts towards any assessment.

Will I be paid for participating in the research?

No

What is the duration of the research?

The study began in December 2012 and final reports will be available in September 2015.

Where will the focus groups and activities be conducted?

In a quiet room in your school and in the classroom you normally work in with your teacher.

Will the outcomes of the research be published?

It is anticipated that results will be provided in a report, which you can ask to see. A thesis will also be submitted to the School of Education and available to you upon request.

Contact for further information

amanda.banks@postgrad.manchester.ac.uk *07879 842910*

What if something goes wrong?

If a participant wants to make a formal complaint about the conduct of the research they should contact the Head of the Research Office, Christie Building, University of Manchester, Oxford Road, Manchester, M13 9PL. You may also contact Drew Whitworth who is supervising this project: Drew.Whitworth@manchester.ac.uk.

Raspberry Pi and Computing Education

CONSENT FORM

If you are happy to participate please complete and sign the consent form below

I confirm that I have read the attached information sheet on the above project and have had the opportunity to consider the information and ask questions and had these answered satisfactorily. ☐

I understand that my participation in the study is voluntary and that I am free to withdraw at any time without giving a reason and without negative effect to me ☐

I agree to take part in two focus groups, one before and one after the activity and to be audio recorded during the activity ☐

I agree to take part in the above project

Name of participant Date Signature

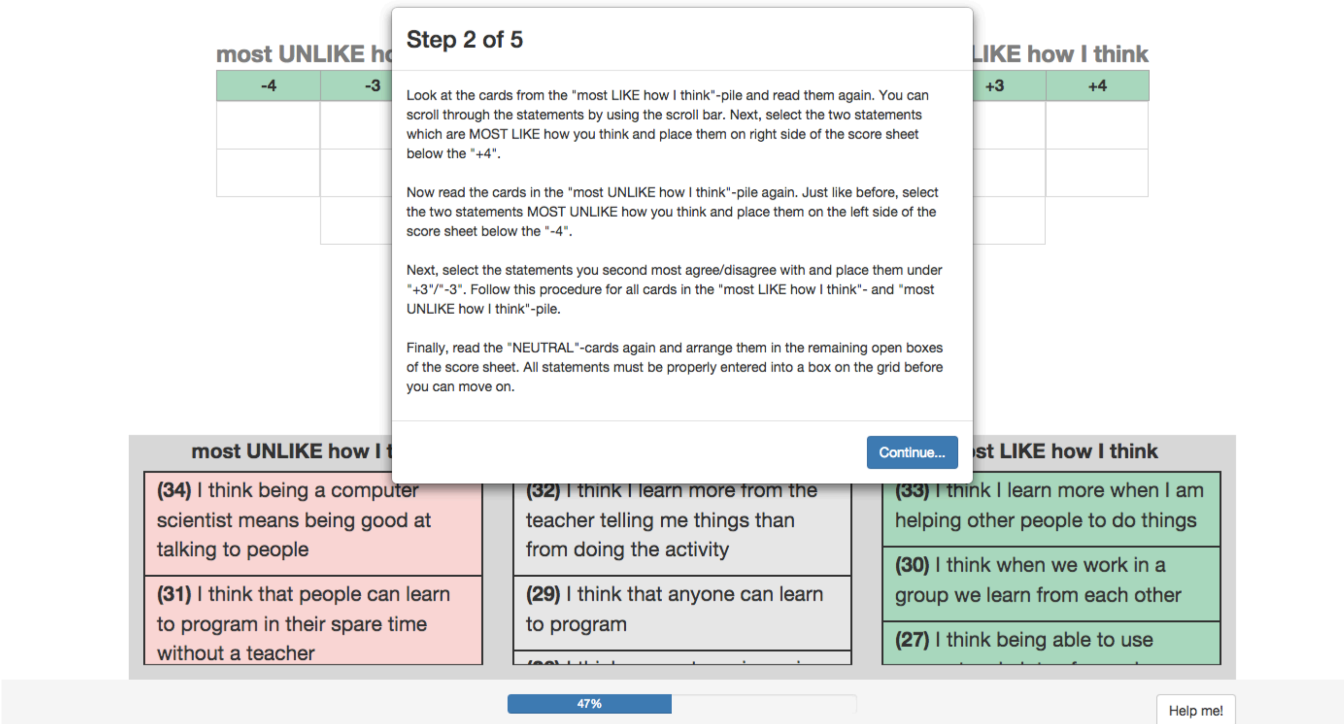
Name of person taking consent Date Signature

Appendix D – Observation schedule

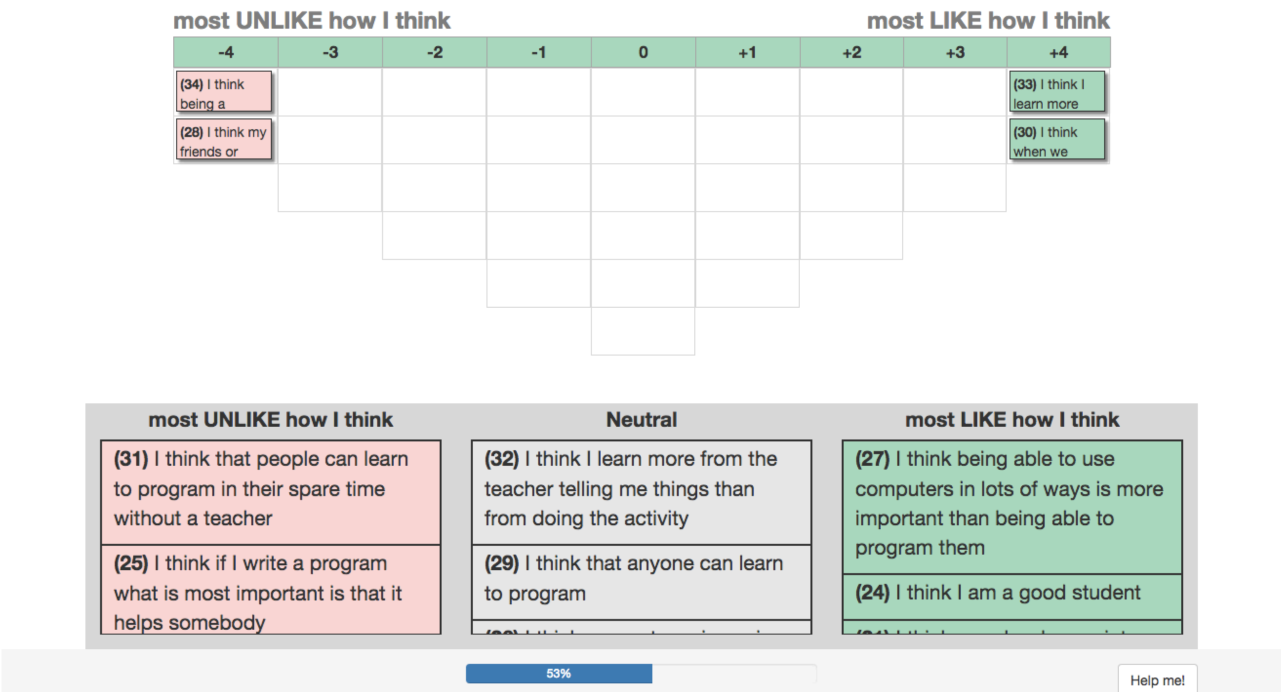
School *(type, SLT relations)*	
Teacher *(background, position in school, perspective on new curriculum, approach to pedagogy)*	
Setting *(lesson, club)*	
Project *(objectives, practicalities)*	
Date	
Environment *(room layout, equipment)*	
Attendees *(demographic, seating, relations)*	
Lesson/session pedagogy • *Objectives (what are they; explicit or not?)* • *Lesson/session structure (starter/plenary etc., directive or opportunisitic)* • *Teacher talk type (expositions, questioning)* • *Teacher talk understanding (how - if any - attempts to narrow colloquial/literate discourses)* • *Pupil response to teacher talk* • *Pupil discussions relating to technology* • *Pupil discussions relating to understanding* • *Pupil achievements* • *Difficulties (with equipment, other practicialities)*	

Appendix E – Online Q sorting

Screen 1

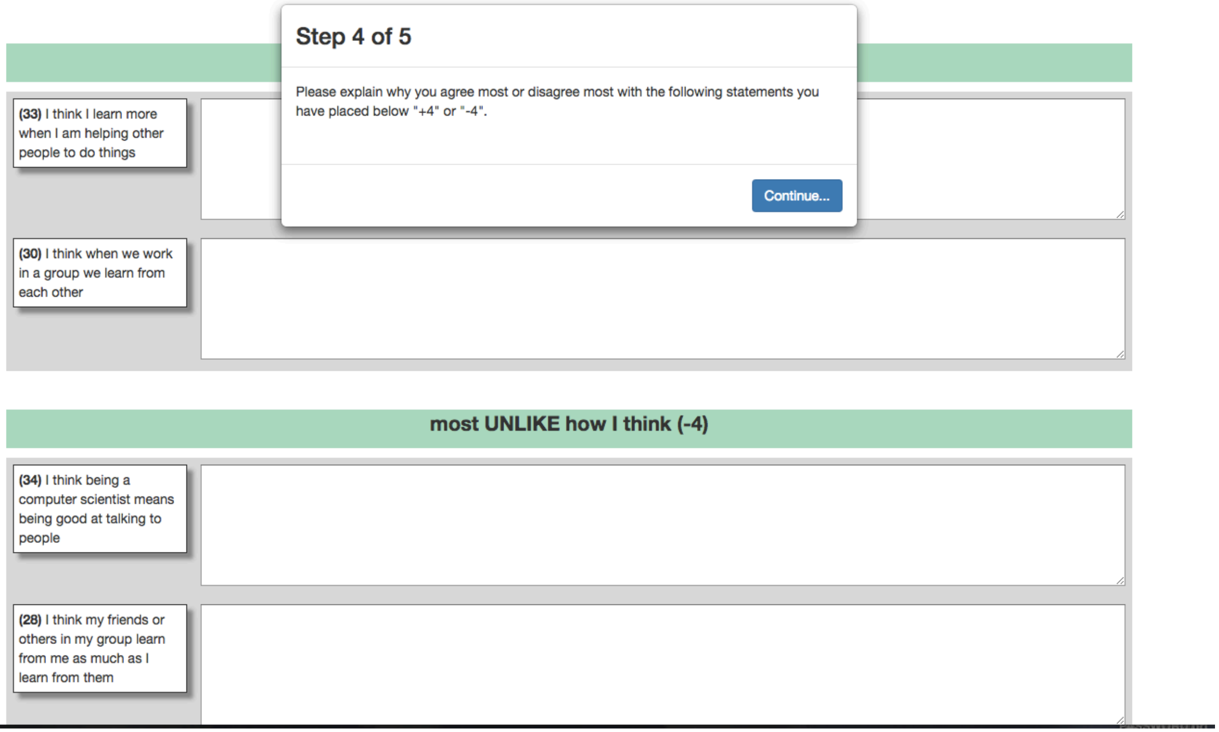


Screen 2


most UNLIKE how I think
most LIKE how I think
-4
-3
-2
-1
0
+1
+2
+3
+4
(34) I think being a
(28) I think my friends or
(33) I think I learn more
(30) I think when we
most UNLIKE how I think
Neutral
most LIKE how I think
(31) I think that people can learn to program in their spare time without a teacher
(25) I think if I write a program what is most important is that it helps somebody
(32) I think I learn more from the teacher telling me things than from doing the activity
(29) I think that anyone can learn to program
(27) I think being able to use computers in lots of ways is more important than being able to program them
(24) I think I am a good student
53%
Help me!

Screen 3

Screen 4


Step 4 of 5
Please explain why you agree most or disagree most with the following statements you have placed below "+4" or "-4".
Continue...
(33) I think I learn more when I am helping other people to do things
(30) I think when we work in a group we learn from each other
most UNLIKE how I think (-4)
(34) I think being a computer scientist means being good at talking to people
(28) I think my friends or others in my group learn from me as much as I learn from them

Appendix F – Parallel analysis

BEFORE

Factor	Actual	Parallel mean	Parallel 95th %
1	5.8902	3.21254839	3.61832794
2	4.4265	2.8061199	3.0708003
3	2.4099	2.49941736	2.70573655
4	1.7168	2.25019137	2.43063692
5	1.6351	2.0424756	2.21153549
28	0.0111	0.0140934	0.02784971

AFTER

Factor	Actual	Parallel mean	Parallel 95th %
1	6.3721	3.21254839	3.61832794
2	3.6879	2.8061199	3.0708003
3	2.8178	2.49941736	2.70573655
4	2.0266	2.25019137	2.43063692
5	1.8008	2.0424756	2.21153549
28	0.0072	0.0140934	0.02784971

The parallel analysis ran a PCA extraction on the Q sort data and a PCA with SPSS with 1000 random data set. These tables show the unrotated eigenvalues observed in the data set of each study. The right hand column shows the95th percentile eigenvalues (or the 950^{th} highest eigenvalues) from the 1000 random data set. This process aids decisions on how many factors to extract, as according to Watts and Stenner (2012), where the observed eigenvalue exceeds the 95^{th} percentile eigenvalue in the parallel analysis, there is a less than 5% chance that this observed value could have occurred with random data where there are no factors.

The table above demonstrates that in the Before study, the eigenvalue of factors 1 and 2 exceed the 95th percentile of the parallel, and in the After study factors 1, 2 and 3 exceed the 95th percentile. However, this is purely guidance for which factors are likely to be significant and worthy of investigation. As explained in chapter 5, Q analysis situates the researcher as central and thus the parallel analysis can be used as a starting point for which factors to extract, before exploring other solutions. In this analysis, I explored the data of two, three, four, five and six factor solutions for each study before settling on four for each study, based on knowledge of the broader context of the study.

Appendix G – Statement Coding

	Efficacy/legitimacy	Ways of knowing	Values/LC	Connection
Self	(1) I think I know how to program a computer	(16) I think I can improve how I learn about computing	(23) I think if I write a program what is most important is that it works correctly	(8) I think I will use in the future what we are learning
	(4) I think I could build a device that controls something	(32) I think I learn more from the teacher telling me things than from doing the activity	(25) I think if I write a program what is most important is that it helps somebody	(10) I think I understand how the technology I use every day, like my mobile phone, works
	(7) I think I could teach somebody else how to program a computer		(24) I think I am a good student	(17) I think learning about how computers work is really important for my future
	(22) I think I have a good idea of what I want to do after I leave school			
	(13) I think I know more about computers than most people my age			
School	(30) I think when we work in a group we learn from each other	(2) I think what I learn is more important to me than the grades I get	(14) I think others think I am good at working in a team	(5) I think I can see how what we are learning will is relevant to other subjects I study at school
	(21) I think people who are into computers are seen as geeky	(11) I think doing well in tests and exams is the most important thing in school	(33) I think I learn more when I am helping other people to do things	(19) I think I can improve marks I get in all subjects through learning about computing
	(6) I think friends who haven't done this activity would/will be impressed to hear what we are doing	(31) I think that people can learn to program in their spare time without a teacher	(28) I think my friends or others in my group learn from me as much as I learn from them	

Subject	(20) I think computer science is a really hard subject	(29) I think that anyone can learn to program	(3) I think people who can program computers are more powerful than those who can't	(26) I think computer science is like maths and physics more than it is like history, sociology, citizenship
	(34) I think being a computer scientist means being good at talking to people	(12) I think computer science is about building computers	(9) I think people who make and program computers can make the world a better place	(27) I think being able to use computers in lots of ways is more important than being able to program them
		(15) I think computer science is about making software		
		(18) I think computer science is about solving problems		