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SOLE Coding: Towards a Practitioner-Led Development Framework for the Teaching of Computational Thinking

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Introduction

In 1993, Michael G Fullan, the well-known educational author and authority on educational reform published a paper called *Why Teachers Must Become Change Agents*. This widely cited work argued that "to have any chance of making teaching a noble and effective profession—teachers must combine the mantle of moral purpose with the skills of change agentry" (p.2). By moral purpose Fullan meant 'making a difference' and at its heart was a call for a new conceptualisation of professionalism which put the untapped resources of teachers as the central driver for change in the future of education systems.

Twenty years later another award-winning commentator, Prof Sugata Mitra, was taking to the educational stage. He also offered a vision on the future of learning, only this time, the teacher was almost nowhere to be seen. "The teacher sets the process in motion and then she stands back in awe and watches as learning happens" claimed Mitra in his 2013 TED talk, ideas from which earned him the first 1 million dollar TED prize (Mitra, 2013a).

Mitra asks what teachers are preparing students for, which is contextualised in his well-known work on Minimally Invasive Education (Mitra, 2003) and most recently, Self Organised Learning Environments (SOLE), described as "the first step towards preparing our children for a future we can barely imagine" (Mitra, 2013).

SOLE grows out of the results of research called the ‘Hole in the Wall experiments’ (Mitra, 2003; 2005), where ATM-like Internet-connected computers were placed in walls in the streets of Indian slums. Local children left entirely unsupervised were observed (from afar) to teach themselves how to use the computer, the Internet and teach themselves about various subjects of their choosing. Research showed that children could become computer literate and achieve comparable scores to children who studied the computer curriculum and other subjects (Inamdar 2004; Mitra, 2005). Results in other experiments showed that children performed ‘hard’ problems better in groups than they did individually and capable of researching effectively using the Internet (Inamdar & Kulkarni, 2007; Mitra & Dangwal 2010; Mitra & Quiroga 2012). In sum, these experiments demonstrated that children could learn in groups, with the Internet and without a teacher.

Today, Mitra’s work in India continues and beyond that immediate context also translates into the concept of SOLE, a space where “educators encourage students to work as a community to answer their own vibrant questions using the Internet” (Mitra, 2014). SOLE shares commonalities with personalized and student-led learning but is distinguishable through its focus on emphasizing the convergence of social, intellectual, academic conceptual and physical space for learning to take place, rather than prescribing specific teaching methods. Its universal methodological principles are to stimulate curiosity and engagement in learning content, a social and collaborative atmosphere and peer-interest. SOLE-based learning is stimulated by the introduction of a “Big Question” - an often unanswerable question which initiates big picture thinking and allows children to go off in a range of directions.

In facilitating SOLE spaces, the principles of curiosity, collaboration and peer interest are fuelled by adult encouragement and admiration but not by direct intervention. Thus, based on the 'Hole in the Wall' experiments, SOLE follows 'minimal invasion' from the teacher, whose role is changed from transmitter to facilitator of learning content.

SOLE is not an isolated solution to access to education in the developing world but builds on research into children's innate curiosity and ability to learn independently of a teacher using computers, and the vital role that technology can play in improving learning outcomes and quality of education. The notion of minimal teacher 'invasion' links to the enacting of the learning process during a SOLE but does not limit the role, expertise and craft of the teacher in the design for learning and its assessment. Therefore, as Mitra recently said, "the absence of the teacher can be a pedagogical tool" (2013b).

SOLE as Change Enabler

In this chapter, the Big Question we ask is this: What are the implications of SOLE for creating the coding generation? In doing so, we critically engage with the big picture of the future contribution of primary teachers in the development of the UK primary computing curriculum. Our work is motivated by how innovations in classroom practice like SOLE can leverage the *priming* of primary aged children into a more holistic and deeper understanding of coding through computational thinking. Computational thinking as defined by Wing (2006) is a set of thinking patterns that includes understanding problems with appropriate representation, reasoning at multiple levels of abstraction, and developing automated solutions (i.e., solutions that could be implemented using computers).Our work is based on the premise that computational thinking is an essential skill that should be mastered by the computer programmer (the future coding generation). Central to our approach is that non-computing specialist teachers can be the agents for change in creating the coding generation. SOLE is adopted as both the object and subject of student *and* teacher development. We position SOLE as a powerful enabler for teachers to inquire into the role of computing in their own and their students' development and more broadly as way to engage in deeper discussions about the pedagogical implications of curriculum change.

Fullan's model of educational change focuses on the roles and strategies of various types of change agents and asks the Big Question: What can different stakeholders do to promote change that addresses their needs and priorities? To enable us to move beyond a descriptive account of the implications of SOLE, we used Fullan's work to provide us with a holistic conceptual approach for framing our work. The chapter is organised around 4 core capacities identified by Fullan as required for engagement with curriculum change: personal vision; mastery; inquiry and collaboration (1993).

These capacities provide a way through which we, the SOLECODE research team, planned, designed, implemented and reflected on the use of SOLE to teach students about computational thinking in a six-week after school club in a primary school in the North East of England in November to December 2015. The SOLECODE team included a primary teacher in his first year of teaching, an educational researcher specialising in SOLE, two computing science researchers, a software programmer, a human-computer interaction expert, with advice from Prof Sugata Mitra.

Why SOLECODE

In September 2014, computational thinking was introduced to all stages of the UK Computing National Curriculum. As a way of advising on the change to the teaching of computer science, Computing at School produced a number of guides, including one which put on computational thinking at its heart. The guide is presented as helping teachers cope with change and overcome the challenges of bringing this new subject into schools, help them learn new vocabulary, skills and way of teaching (Csizmadia et al. 2015).

Late 2014 was also the same time as the inauguration of SOLE Central, a new research centre set-up to extend intellectual understandings of the concept and broaden the scope of SOLE-based research. Researchers in the centre had been reflecting for some time on how a vision of the UK Computing National Curriculum, and particularly computational thinking, could be taught by non-computing subject specialists. A few months later, when a SOLE Central researcher was contacted via Twitter by a local primary teacher, Chris, who wanted to share news that he had started his own afterschool 'SOLE club', the seed for the project was sown.

Planning and designing for the club involved synthesizing our personal visions and working collaboratively to think about about the role and relevance of SOLE, our research practice and its relationship to computational thinking. Implementing a SOLECODE learning design involved further collaboration and discussion about what worked and didn't work. In this sense we were able to develop a sense of mastery over teaching computational thinking through SOLE and particularly by reflecting together, re-sharing and revisiting out personal visions as a form of inquiry. Evaluation involved a specific inquiry into the facilitation of SOLECODE and focussed in on Chris' own views feeding into his development and change agentry.

Personal Visions

> *"Working on personal visions means examining and re-examining why we came into teaching. Asking "What difference am I trying to make personally?" is a good place to start"* (Fullan, 1993).

Chris' initial interest in SOLECODE was rooted in his belief in the importance of creativity in teaching and learning.

> *"rather than the old methods of teaching where the teacher stands at the front and delivers knowledge, for me teaching is about sparking students' interest and creativity - with an idea, a concept or a metaphor. I want to support my students to take ownership over their own learning and their own creativity. Learning is not just about acquiring a discipline knowledge base but it also has a social purpose. This is important at primary level because it is so important at tertiary level – taking ownership of one's own learning is a lifelong skill. At tertiary level my own experience was that I lacked the ability think about my own learning, stand up and present my ideas and defend them. The earlier you can introduce the skills and ideas to children that they are in charge and responsible of their own learning the better. I' m not there to ensure they pass the test or do well, I'm there to give them the tools to do so and to achieve what they can"*

From the perspective of the SOLE Central researchers, there was also a sense of a personal vision for the project informed by their own conceptions and experiences (related to moral purpose) of teaching and learning as students, teachers and researchers of computing science and education. The researchers had a shared vision on SOLE integration, which was to extend its intellectual understandings through partnership working and to explore how SOLEs are made material in local contexts.

From the conception of the project, the SOLE Central team and Chris worked together closely to co-design the initial outlines for the SOLE sessions and emerged as the ‘SOLECODE research team’. Our shared vision was one in which the talk around learning computing and computers was turned upside down. We wanted to challenge the popular notion that technological and computing knowledge was something magical and mysterious, needing to be learned for a better future. Our vision placed the child as the protagonist who interrogates the computer’s ability to think, knows its computational limitations, and themselves build one better than we have now.

Collaboration

“the actions of individuals and small groups working on new conceptions intersect to produce breakthroughs” (Fullan, 1993).

Our aim for SOLE CODE was that it could become an example of a learning environment with a power structure and dynamics very different from the traditional classroom. SOLECODE was a judgment-free conceptual and physical space where:

- an after-school club took place with no grades associated with it
- teacher/s were not subject experts
- the problems explored in the sessions did not have a solution (by experts)
- students could quit at any point

- Progression (in its very pragmatic sense) in this environment was attributed to the intrinsic motivations and engagement of the teacher and the students.

We decided that the sessions should take place in a regular classroom using the original classroom layout already set out for different configurations for group work, Each table (6 in total) had a laptop with Internet access and the Big Question for each week was displayed on a large white board. The reduced number of computers and the shared board were part of the SOLE guidelines to create a collaborative environment (Mitra, 2014). The children were free to work with whomever they chose and could change groups at any time. A sharing and collaborative attitude was encouraged and the children were reminded of this at the start of each SOLE.

INSERT FIGURE 1 (Figure 1: The SOLECODE club in action)

Our plan included the Big Question, suggested facilitation and debrief questions. We (Chris and the other ‘assistant facilitators’ from SOLE Central) modified the plans ‘on the fly’ during the sessions. After each SOLECODE session, we also had an open conversation, where the children’s engagement and our facilitation practice was discussed.

Through our examination and discussion about existing methods used in primary teaching, Chris’ interest in creativity and other materials we found which were being used in the teaching of computational thinking, we decided to explore SOLE as a complex system for knowledge production rather than focusing on one aspect (i.e. a ‘teacher-less’ environment). Using the concept of ‘learning design’ we introduced several elements to our outlines to embrace the dynamic nature of this environment. This included offering various material resources to be used by the children to produce the outcomes. This was one of the main departures we made from the original SOLE approach was the introduction of material resources and the use of them by the children in answering the Big Questions.

What is a thought? What is thinking? Can a computer think for itself?

In the first two sessions respectively, we asked the children: What is a thought? What is thinking? In the second session, a further Big Question emerged from the children: Can a computer think for itself? The children had the option of producing their answers using pen and paper, MS Word, or MS PowerPoint applications and exploring in direction they wished. These Big Questions had the objective of motivating the children establish an analogy (or lack thereof) between human thinking and computer thinking. We thus embraced the classic view of creating the computer to replace the human.

What is a computer Bug?

INSERT FIGURE 2 (Figure 2: A computer bug)

The third session proposed the concept of ‘metaphors’. The children were encouraged to produce the answer to the question in LEGO bricks.

Non-programmable LEGO bricks

We introduced LEGO bricks as a resource to produce SOLE outcomes (regularly produced in schools using pen and paper, or MS Office). The choice of non-programmable LEGOs aimed at encouraging conceptual thought processes rather than learning a programming tool. We envisioned that the LEGO affordances would encourage the children to think about modules and abstractions more than on paper or a word document.

We designed this SOLECODE session to introduce the concept of metaphors as a method for expressing ideas and thoughts in order to help the children get comfortable building LEGO models ‘far from perfect’ and imagining stories around them. Inspiration for this was also informed by Mitra’s early work on using the notion of computer bugs in a minimally invasive educational environment to teach programming. Moreover he also used computer bugs as a training tool in the development of a diagnostic method for computer programming training which involved trainees detecting bugs purposely put into a computer programme (Mitra & Pawar, 1983).

What is the P vs. NP problem?

The fourth SOLECODE session introduced the notion that ‘computers cannot do everything we want them to do’. In this session, we decided to challenge some of the perceptions around the capability of computers. Continuing with the theme of creativity and put simply, this Big Question asks whether computers can be taught to think for themselves. The question has at its base one of seven Millennium Prize Problems set out by the Clay Mathematics Institute referred to as the problem of P vs NP. Introducing this problem engaged the children in a major area of research around the search for solutions to problems which seem easy to make up but require an intractable amount of time to solve. P is the class of computing problems solved in polynomial time - which is easy for a computer. NP is the class of computing problems that could be solved

3-coloured graph problem: A graph consists of connected blank areas (Figure 3). A graph is x-coloured if x is the minimum number of colours could be used to colour in the blank areas so that no two adjacent areas (sharing a border) have the same colour. The children were given several sheets for multiple graph examples and were asked to find out whether these graphs were 2-coloured or 3-coloured. The multiple sheets were provided to encourage them to try several different solutions.

in polynomial time by a nondeterministic Turing machine – so a computer could easily verify its solution but there is no efficient way of obtaining the solution in the first place. The Millennium Prize Problem therefore asks whether a problem whose solution could be *verified* in polynomial time, could be also *solved* in polynomial time.

The children first explored the question with only the Internet made available to them as an external material resource. We then integrated a classical graph colouring problem as a practical example for P and NP problems, taken from a series of resources from CS Unplugged called 'The Poor Cartographer' (http://csunplugged.org). The use of the graphs (equivalent to paper-based colouring maps) was introduced to the children as one way in which people try to represent computational thinking.

INSERT FIGURE 3 (Figure 3: An example for a 3-colourable Graph with the correct minimum number of colours)

Our aim was to make the problem tangible by offering an example for simple and complex problems. We wanted to encourage the children to grasp where complexity comes from when it comes to computing. The overall aim was to encourage the children to find the rules they used to solve the problem for themselves. In later SOLECODE sessions, we hope that they would use these to engage in the application of them when addressing further Big Questions.

What does the computer of the future look like which could solve the P vs. NP problem?

The fifth and the sixth SOLECODE sessions focused on 'making the computer of the future' (the hardware and software), our computational thinking aim was to encourage the children to engage in learning about the computer from the 'inside' as well as engage in discussions about solving a complex problem. (P vs. NP). We therefore invited the children to respond by designing the computer of the future, one that could solve the P vs. NP problems using LEGO bricks. In addition to the bricks, we provided the children with a keyword sticker list from UK National Computing Curriculum, which could be used (if they chose) to help with Internet searches and the construction with the computer. Empty stickers were provided so they could label their own computer pieces.

INSERT FIGURE 4 (Figure 4: A computer of the future)

The UK Department of Education (2013) says that "A high quality computing education equips pupils to use computational thinking and creativity to understand and change the world" (p. 217). Echoing this, SOLECODE was co-designed to encourage the children to adopt a critical perspective towards computing and impact the *route* rather than the rate through which they learned how to code. Our design does not aim to discourage children by the "bugs" they encounter at the beginning of their learning, rather it is designed to trigger curiosity to learn why these errors happen and how they can fix them in a self-organised way. Figure 5 shows a visual outline of all 6 SOLECODE sessions reported here. SOLECODE 7 is an additional session which we envisage adding to future sessions.

INSERT FIGURE 5 (Figure 5: A outline of the SOLECODE learning design)

The SOLECODErs

We initially had 24 children aged between 9 and 10 years old (Key Stage 2) sign up to the afterschool club, whose abilities were marked by their class teachers as follows (six high ability, 12 middle-ability, six low-ability, and one special educational needs). Twenty children participated up until the last two sessions (10 males and 10 females).

INSERT Figure 6 (Figure 6: The SOLECODE Generation)

Inquiry

"inquiry - indicates that formation and enactment of personal purpose are not static matters but, rather, a perennial quest" (Fullan, 1993)

Our SOLECODE learning design, based on SOLE principles, provided the instructional ingredients for teaching computational thinking. However, this was only one part of project. In implementing it, our primary interest and focus was on developing SOLECODE as a mediational tool – as an enabler for the teachers' change agentry. This meant exploring the notion of pedagogical intent in the enactment of our shared vision. For this, our collaborative inquiry, led by Chris, was central.

Chris' initial interest in SOLECODE was rooted in how it embraced current changes in education, but this also came with a number of questions:

> *"The government says that the new Computing Science National Curriculum has a real freedom for teachers to decide how best to teach. Taking this into consideration and the radical changes spurred on by innovations in technology I'm intrigued about the idea of teaching in a chaotic child led environment like SOLECODE. Although exciting, it does bring a plethora of new questions such as; how do I know learning is taking place? How*

do I assess progress and attainment? In what ways do I evidence this new type of learning?"

As part of the collaborative inquiry, Chris identified two key areas that he wanted to explore, re-visit and discuss during the SOLECODE sessions:

1) Develop an understanding and competence in the delivery of SOLECODE

> *"I'm concerned about how the delivery of SOLECODE will be very different from my day-to-day teaching role. With the children being in such control of the direction of the lesson, I'm going to have to map out and adapt my questioning to ensure the children cover the topics and learning required before progressing to the next session"*

2) Develop an understanding of what learning in a 'chaotic' SOLE-like setting looks like

> *"I think my role of teacher is going to drastically change in SOLECODE, I'm going to have to step back and assume the role of a mediator. I'm worried that by giving the children completely free reign, it will be too chaotic and they'll learn nothing*"

Over a number of sessions, these areas became a central part of the inquiry and fed into the implementation. Often, they provided a specific focus for the post-session conversations, where we reviewed individual sessions and made plans for how we might modify the next and develop facilitation techniques. After the second SOLECODE session, Chris wanted to devote some specific time to explore his development, so we decided to document the activity in the sessions using photographs. The idea was drawn from participatory approaches to research which use visual methods to build shared understandings of concepts and activities (Clark et al. 2013).

Chris ranked photographs taken by other members of the SOLECODE team as a way of exploring and clarifying his growing facilitation of the sessions and particularly the nature of quality of the children's learning. This activity revealed a number of interesting points about engagement and different teacher-student student-student interactions emerging in the SOLECODE environment.

Figure 7 zooms in on a closer look at the images with Chris' commentary, where he chose to rank the photographs according to two concepts: engagement and narrative of events.

INSERT Figure 7 (Figure 7: SOLECODE Diamond Ranking Activity 1)

In the last SOLECODE session, Chris documented by taking photographs himself (Figure 8), then in discussion with another member of the team, performed another ranking exercise. This revealed a further focus on engagement but also a deeper discussion about the role of the teacher. This deeper discussion demonstrated a more significant focus on how the learning environment and namely the facilitation of the SOLECODE sessions was inextricably linked to progression and the nature of learning outcomes.

INSERT Figure 8 (Figure 8: SOLECODE Diamond Ranking Activity 2)

Mastery

"Beyond exposure to new ideas, we have to know where they fit, and we have to become skilled in them, not just like them" (Fullan, 1993)

Fullan's characterisation of mastery as one of becoming skilled in ideas and not just liking them is just as relevant now as it was more than twenty years ago. This is echoed in the concluding remarks in the guidance for primary teachers Computing At School (Berry, 2013):

> *"It's a really exciting time to be a primary school teacher, too. Don't be daunted by the changes in the move from ICT to computing. Rather, see this as an opportunity to develop your own knowledge about computing and to learn to program, if you've never had the chance before. Although this might sound like hard work, it's actually great fun. You'll find that you make better use of the technology you have at home and in school, and also that you start to think a bit differently, looking at systems and problems in the same way a computer scientist does"*

The SOLECODE project provides insights into how the translation of ideas into actions can take place through collaboration and inquiry. The SOLECODE learning design was to large extent informed by Chris' personal belief that teaching is about sparking students' interest and creativity. By working together, the SOLECODE team began to think differently about computing in and out of school, as well as the research lab, to create the SOLECODE learning design.

Chris' inquiry showed that for the teacher, SOLECODE became a mediational tool for understanding the teaching and learning of computational thinking as a situated process. SOLECODE became a physical and intellectual space to extend on understandings about the teacher development in computing from exclusively based on skill development in the mastery of subject knowledge to one of *appropriation*. Appropriation is closely tied to Fullan's definition of mastery and moral purpose. According to Wertsch, appropriation is a "process of taking something that belongs to others and make it one's own" this is contrasted with mastery which is "knowing *how to* use an artefact" (1998, p. 53). Here, artefacts are physical and intellectual "signs, symbols and tools" (Instefjord, 2015, p. 315) a category to which we believe SOLE belongs. The process of appropriation begins with "an initial contact with something that is not familiar to us" and as we progress in using new artefacts we begin to "investigate the different aspects of how the artefact mediates" and "learn new ways to use it and we discover new functions that we did not recognize in the beginning" (Instefjord, 2015, pp. 315-316). In time, this artefact becomes appropriated and we no longer need help from others.

To conclude, we return to our Big Question posed at the beginning of this chapter: what are the implications of SOLE for creating the coding generation? Our inquiry has shown that SOLECODE provided a context for the development of new ideas about the teaching of computational thinking in ways which have yet to be explored in computing education in the UK and elsewhere. But, as Chris concludes, change agentry does not come without challenges, it demands creativity, trial and error and personal strength. Ultimately, these are all values which the future coding generation made up of teachers and students also need to learn:

> *I remember sitting in a training session being told that we had to teach children about algorithms and coding and we all just kind of looked at each other. I remember some very vague lessons plans were handed to us that we were not at all confident in teaching. What I've learned from my SOLECODE experience is that it is not as scary as you might think it would be to teach something like computing science when you don't feel 100% sure about what it is. I've learned along with the kids: I've learned to embrace that fear of 'not knowing all' and just get on with it, experiment and learn by trialling things – teachers can be self-organised learners too!*

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