Unplugged Computing and Semantic Waves: Analysing Crazy Characters

Jane Waite
Queen Mary University of London
j.l.waite@qmul.ac.uk

Karl Maton
The University of Sydney
karl.maton@sydney.edu.au

Paul Curzon
Queen Mary University of London
p.curzon@qmul.ac.uk

Lucinda Tuttiett
Barefoot Computing
lucinda.tuttiett@swgfl.org.uk

ABSTRACT

We explore how Legitimation Code Theory, and, in particular, semantic waves, provides a useful way to understand what makes unplugged computing activities effective (or not) in the classroom. We overview the theory, discuss how it applies to unplugged activities, and describe a case study where we apply it to a specific, widely used, unplugged activity. In particular, we show that the published lesson plan follows a semantic wave. We suggest that semantic waves are useful both in developing and reviewing lesson plans around unplugged (and other) computing activities. They also have great potential in teacher training and continuous professional development of computing teachers.

CCS CONCEPTS

• **Social and professional topics → Computer science education**; **K-12 education**; *Computational thinking*; *Computing education programs.*

KEYWORDS

Unplugged computing, semantic waves, semantic profile, Legitimation Code Theory

ACM Reference Format:
Jane Waite, Karl Maton, Paul Curzon, and Lucinda Tuttiett. 2019. Unplugged Computing and Semantic Waves: Analysing Crazy Characters. In *UK & Ireland Computing Education Research Conference (UKICER), September 5–6, 2019, Canterbury, United Kingdom.* ACM, New York, NY, USA, 7 pages. https://doi.org/10.1145/3351287.3351291

1 INTRODUCTION

To teach well, it is important to understand what makes a good or bad learning experience. A variety of pedagogical approaches have been suggested as ways to teach computer science effectively. In the school environment there is limited research, however, into what is effective pedagogy in computing lessons [Waite 2017]. 'Unplugged' Computing has been one of the more popular approaches espoused, especially with respect to primary and secondary (K-12) school education. However, concrete evidence as to its effectiveness has been mixed [Rodriguez et al. 2017; Thies and Vahrenhold 2016].

Legitimation Code Theory (LCT) provides a promising approach to help understand the effectiveness of teaching. It introduces the idea of 'semantic profiles' that show how the context-dependence and complexity of meanings change over time [Macnaught et al. 2013; Maton 2013, 2014; Maton et al. 2016]. It also introduces 'semantic waves' as an effective means to analyse lesson activities: recurrent movements between simpler and more complex, and concrete and abstract forms of knowledge. Curzon et al. [2018] argue that structuring explanations and activities following the semantic waves approach is behind successful teaching by analogy, storytelling and unplugged teaching in computing. We investigate this claim here focusing on unplugged activities.

Unplugged activities, in which teaching of computing is done away from computers, are naturally constructivist [Piaget 1971] in nature and can also be constructionist [Papert and Harel 1991]. When used in a workshop / whole class activity setting, students build their own understanding through engaging directly in the activities. They can also be used in a purer explanatory way as demonstrations. Constructionism and constructivism give some insight into why they might or might not be successful. However, even a single unplugged activity can be used in a variety of different ways. A way to do a more fine grained analysis of a lesson plan may give deeper insight. We argue that LCT provides a useful theoretical framework, and semantic profiles a practical analysis tool, to do this. The use of the semantic profiling tool here is aimed at the computer science education research community.

The contribution of this paper is to apply LCT to Computer Science teaching using, as a case study, a concrete and popular unplugged activity aimed at primary school children. In particular, we examine the semantic profile of the written lesson plan. We show that the unplugged activity does indeed represent a semantic wave, exploring in detail how it does so. In doing this we show that LCT provides a useful way to analyse lesson plans that gives insight into the way learning activities support students to unpack and repack new abstract concepts. We argue that semantic profiles provide a powerful way to reflect on, and understand, the effectiveness of unplugged activities, as well as computing activities more generally.

UKICER, September 5–6, 2019, Canterbury, United Kingdom

ACM ISBN 978-1-4503-7257-2/19/09…$15.00
https://doi.org/10.1145/3351287.3351291

2 SEMANTIC WAVES

The notion of *semantic waves* is part of Legitimation Code Theory (LCT) [Maton 2013] (not to be confused with the 'coding' of programming). LCT provides an explanatory framework for exploring what constitutes a good learning experience (eg what makes an effective explanation). One dimension of LCT is called 'Semantics' and it can be used to analyse how the context-dependence and complexity of meanings develops over time in a learning episode. It has been applied in a variety of disciplines including Biology, Chemistry, History, Journalism, Nursing, English and Physics as noted by Blackie [2014]. (More on Legitimation Code Theory and its use across a variety of disciplines can be found at legitimationcodetheory.com [2019].) Love [2016] has explored how semantic waves can be used to review the use of ICT in teaching and suggests they can reveal why teachers use certain technologies as well as providing a means for teachers to evaluate which tools can help learners become more independent. However, as yet there is little work exploring the usefulness of the approach for computer science education.

We can use semantic waves as a basis to review explanations, as well as more general learning activities. This enables us to abstract the process of learning to better think about how learners develop an understanding of knowledge. The overall aim is that by doing this educators can reflect on, and improve, learning experiences for their students. Foundational concepts related to semantic waves are: *semantic gravity* and *semantic density* (see Figure 1), which we explain in the next sections.

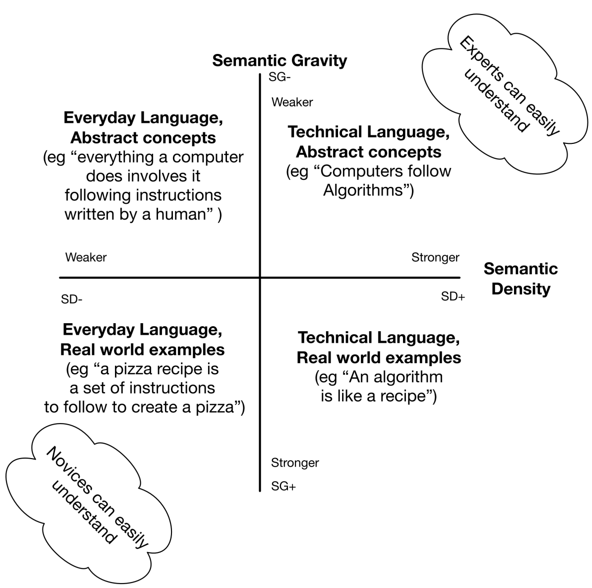

Figure 1: Semantic Density and Semantic Gravity

2.1 Semantic gravity

Semantic gravity is about how contextualised language or examples are for the learner. It explores the *context* of *meanings* and how much *meaning* depends on the *social context* to make sense. So where meanings have greater dependence on the context (such as practical examples or personal experience) semantic gravity is stronger and where meanings are more abstract (such as theory), semantic gravity is weaker. Changes in semantic gravity can be shown over time; such as when teachers or students move from theory to examples, or from practical activities to an abstract concept.

For example, an activity with weaker semantic gravity would be to explain what an algorithm is by just giving a definition (eg 'an algorithm is a set of precise rules or steps to solve a problem') and to then expect learners to memorise the definition without any context. Semantic gravity would become stronger by adding an example to the explanation (eg 'an algorithm is a set of precise rules or steps to solve a problem such as an unambiguous set of steps to draw a square'). This shifts the explanation from weaker to stronger semantic gravity.

The learning experience would be strengthened further if learners then engaged in a practical activity of creating algorithms to draw squares where the need for equal length sides was specifically explored to highlight the importance of precision. Such an activity would have even stronger semantic gravity as the learner is engaging in a context that makes the meanings even more concrete in terms of their own personal context.

2.2 Semantic density

Semantic density is concerned with the use of technical and everyday knowledge. It explores the *complexity* of *meanings* rather than their context. Where meanings are relatively simple, such as describing something in everyday language, semantic density is weaker. Where meanings are more complex, such as using technical concepts, semantic density is stronger.

An activity asking learners 'to follow the instructions to draw a square' would have a weaker semantic density than one requiring learners 'to follow the algorithm to draw a square'. This is because the first activity is less complex to understand, as the term instruction has a less complex meaning than the term algorithm, though loses some of the precision.

2.3 Semantic waves

Ultimately we want students to master technical language, holding a deep understanding of the precise meanings they represent; a densely packed understanding. In doing so, learners can then become experts. However, to do this we need to introduce imprecise language and everyday contexts to form a bridge between what learners already know and what they do not know.

Semantic gravity and semantic density go hand in hand as learners build understanding. Experts work in a domain of weaker semantic gravity and stronger semantic density (abstract descriptions in technical language). Novices, however, can find this domain intimidating and impenetrable. Novices may need stronger semantic gravity and weaker semantic density (concrete descriptions in everyday language). The teaching challenge is to help students traverse from novice to expert, from the bottom right to top left of Figure 1.

We can depict changes in semantic gravity and semantic density within a learning experience as a *semantic profile*: a curve showing how the levels change through a definition, exercise or explanation activity. In an example from teaching Biology given by Maton [2013], the teacher begins by discussing a scientific concept in

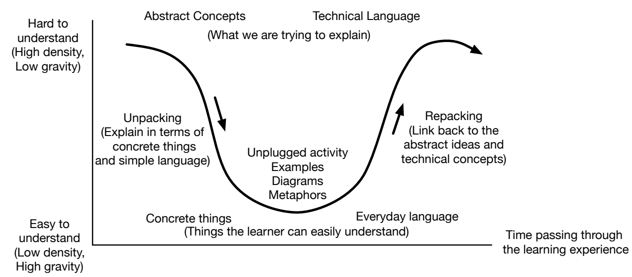

Figure 2: Traversing a semantic wave

abstract and technical terms. The teacher and students then unpack some of its meanings in everyday language through practical, contextualised and concrete examples. Finally, in the activity, the students repack those examples into technical terms by completing a table of concepts. This follows the pattern of Figure 2. It moves from abstract and complex meanings down to more grounded and simpler meanings and then back up to abstract and complex meanings again. This kind of movement, as an explanation or activity progresses, first traversing down, unpacking meanings and then back up to repack them, is one form of what is called a 'semantic wave'. Maton [2013] suggests, and a growing number of studies show, that they are crucial for knowledge building in classrooms. Maton et al. [2016] has investigated such waves across a variety of studies and suggests that such waves enable knowledge to be built, while flatlines (such as continuous description or incessant theorising) hinder knowledge building. A good learning experience follows a series of connected waves, each building on the previous one. Rather than assuming that once a technical, abstract concept has been explained it can be used from there on, good teaching practice involves continuing to traverse the wave recurrently and make the links. These insights are now feeding into teacher training, curriculum planning, and classroom practice.

3 UNPLUGGED COMPUTING

Unplugged computing activities are educational activities that aim to teach computing concepts without using a computer [Bell and Lodi 2019]. Instead, they use physical, kinaesthetic approaches to make the intangible, abstract concepts tangible [Curzon et al. 2009]. This can include a variety of specific approaches including role playing computation in action, games, puzzles, and magic tricks [Curzon and McOwan 2008] as well as story-telling. Analogies and metaphors make links between abstract concepts and physical things that students are already familiar with. Unplugged activities make use of a physical enactment of a concept, rather than relying on mental imagery generated by a verbal description, to contribute to the development of the semantic wave. The physical enactment activates entrenched memories of the familiar, helping to make the links between the abstract concept and familiar concrete ideas [Barsalou et al. 2003] By making intangible, abstract concepts physical, this allows them to be pointed to and manipulated, and facilitates students in asking questions before they have mastered the technical terminology to be precise.

Unplugged activities can be used in different ways. The original CS Unplugged project, by Bell et al. [2009], primarily provided constructivist whole class activities. Curzon et al. [2018] have in addition advocated their use of a powerful explanatory technique. Used in this way they can be used in large class and lecture situations.

Curzon et al. [2018] argues that semantic waves provide a way to understand how to effectively teach computing concepts, and explain why approaches such as metaphor, and unplugged activities can work well, provided a semantic wave structure is followed. Some unplugged activities and the use of analogies and similes (such as that 'an algorithm is like a recipe') have been criticised precisely because they lose precision of meaning of the technical counterpart, and instead introduce simplified, imprecise everyday versions. Used well, however, doing this matches the semantic wave idea of a good learning activity. They naturally build bridges between concrete experiences that are easily understood and the very abstract concepts of Computer Science. However, to be effective, the theory (and experience from other disciplines) suggests that the semantic wave needs to be followed when doing these activities. Students need to be actively engaged to repack ideas themselves, leading them back up the curve to develop more technical, abstract understanding of concepts.

4 A CASE STUDY: CRAZY CHARACTERS

To explore the use of semantic waves to better understand the effectiveness of a computing lesson plan, and in particular an unplugged activity we constructed the semantic profile of a specific activity. This activity, called Crazy Characters is widely used in the UK. Specifically, we reviewed the written lesson plan for the first stage activity of the full lesson, investigating the way the activity would be conducted if exactly following the plan. Crazy Characters was chosen because one of the authors was familiar with it, and because it has been widely used, and is still very popular with teachers. It was also due for a review, with one of the authors asked to undertake this review.

4.1 The activity

Crazy Characters is an online lesson plan which introduces algorithms to primary pupils, aged 5-7, using an unplugged activity. It is one of the free resources available from the Barefoot website [Berry et al. 2019]. In the activity, learners are asked to follow verbal instructions to draw a crazy, made up, character (see Figure 3). The instructions are intentionally not very precise so that learners can then improve the algorithm. Following a whole-class activity, learners then design their own algorithm in order to draw their own crazy character. The full Crazy Character lesson plan can be downloaded from Berry et al. [2019].

4.2 Background

Crazy Characters was first developed in 2012 as a response to changes in the teaching of computing in English primary schools. At this time, the ICT curriculum was disapplied, creating a two-year hiatus when primary teachers had to await a new statutory framework. In the meantime, either the old curriculum had to be delivered or teachers had to start to teach what they thought might come next. The first version of the activity was initially devised by a then primary school teacher (the first author) in response to this dilemma. She then adapted it, in 2014, as a Barefoot Computing

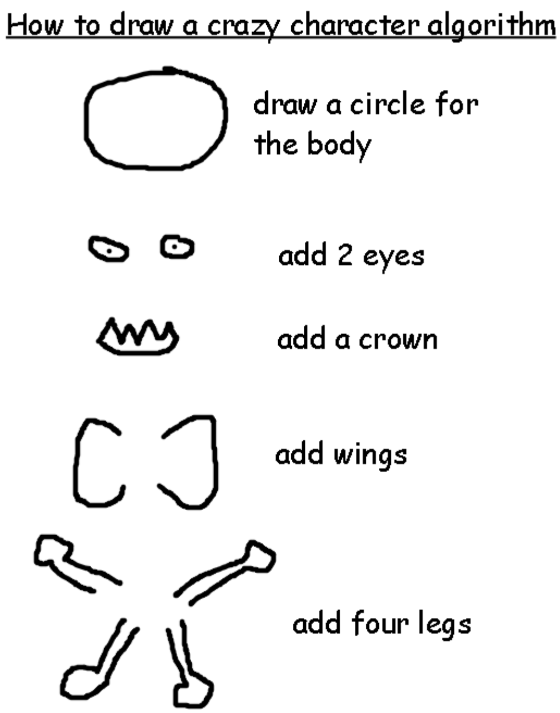

Figure 3: Teachers read out their algorithm of how to draw a crazy character.

Programme resource. Managed by the British Computer Society (BCS), the Barefoot initiative was funded by the UK Department for Education and the Telecoms company, BT. Barefoot was one of the first of many successful, innovative Computing At School (CAS) programmes to support teachers in their delivery of computer science in school in the UK. Crazy Characters was one of the first resources on the Barefoot website, part of the very first continuing professional development (CPD) presentation, and is still a staple of the Barefoot volunteer workshop delivered to teachers in schools.

Requirements for the activity were that it should be easy to run in class, be fun, and most importantly, gently introduce the new word 'algorithm' to primary school students. It should do this by doing rather than by telling. The developer did not at that time know about semantic wave theory, and it was not developed with the theory in mind. Instead the resource was developed using insight from the way its teacher-developer normally taught instruction writing in literacy. This included engaging learners through curiosity, teachers getting things wrong and using humour, creating a gradual accumulation of learning through practical hands on activities and peer review.

4.3 Methodology: Creating the semantic profile

Case studies are a versatile approach for providing an in depth description and analysis of an instance in action [Merriam 2009; Stake 1995].

To produce the case study of an application of LCT on a common classroom unplugged activity, the first two co-authors worked together to analyse the lesson plan and create the semantic profile. One was very familiar with the activity; the other was an expert in LCT. The review was done via an online hangout. The LCT expert first read the lesson plan. They then, together, walked very carefully through the plan step by step, drawing up the semantic profile of each step in turn by examining the semantic gravity and semantic density of the lesson plan instructions. The plan was profiled as though a teacher was following the plan to the letter.

Each lesson plan statement was reviewed in turn and whether there had been a change in semantic density or gravity was considered. The highest point on the profile represented the weakest semantic gravity and strongest semantic density and the lowest point represented the strongest semantic gravity and weakest semantic density. Time spent on each step is approximated along the x axis. The curve of the profile emerged as each step was reviewed and the change was plotted. The profile is therefore a relative and heuristic, rather than absolute, representation and gives an impression of the changes in semantic gravity and semantic density over time. This simplified profiling approach is appropriate for a single exploratory case study [Maton 2014].

4.4 The semantic profile for Crazy Characters

The semantic profile for the introduction part of the Crazy Characters lesson plan is shown in Figure 4. It is broadly a U shape but with staged return coming out of the U. We go through each of the steps of the lesson plan one by one to explain the wave.

4.4.1 Signalling. Initially the teacher explains to students that a special new word is going to be used. Learners are signalled that something important is coming, that a concept high up the semantic profile is on the way. Learners are NOT provided with a definition at this stage. Instead, curiosity and expectancy are kept high, so they can form their own understanding of the term later through practical experience. There is no practical concrete activity going on here so semantic gravity is weaker.

4.4.2 Concept Introduction. The term 'algorithm' is introduced as the teacher starts to use the word; the teacher is instructed in the lesson plan that they should NOT explain what the word means at this point. There is no practical activity here (weaker semantic gravity) but it is clear that the term is a complex and technical one (stronger semantic density).

4.4.3 Connecting. In the plan, the teacher is instructed to say they are going to use the algorithm now. This clear connection of the concept to the activity is very important. The connection enables learners to add the knowledge they gain during the practical activity to their emerging understanding of the meaning of the concept. As shown in Figure 4, the semantic profile line drops, like a bungee rope, as we connect the theory to the practical activity (strengthening the semantic gravity as the context is introduced). If there was no connection, the line on the profile would break.

4.4.4 Concrete activity. Next, the teacher is asked to read out the steps to enable the learners to draw the crazy character. The wave is low on the profile: it is a concrete activity (stronger semantic gravity) and likely to be expressed through relatively simple meanings (weaker semantic density) ... unless learners start to use the term 'algorithm', in which case there would be little spikes in semantic density.

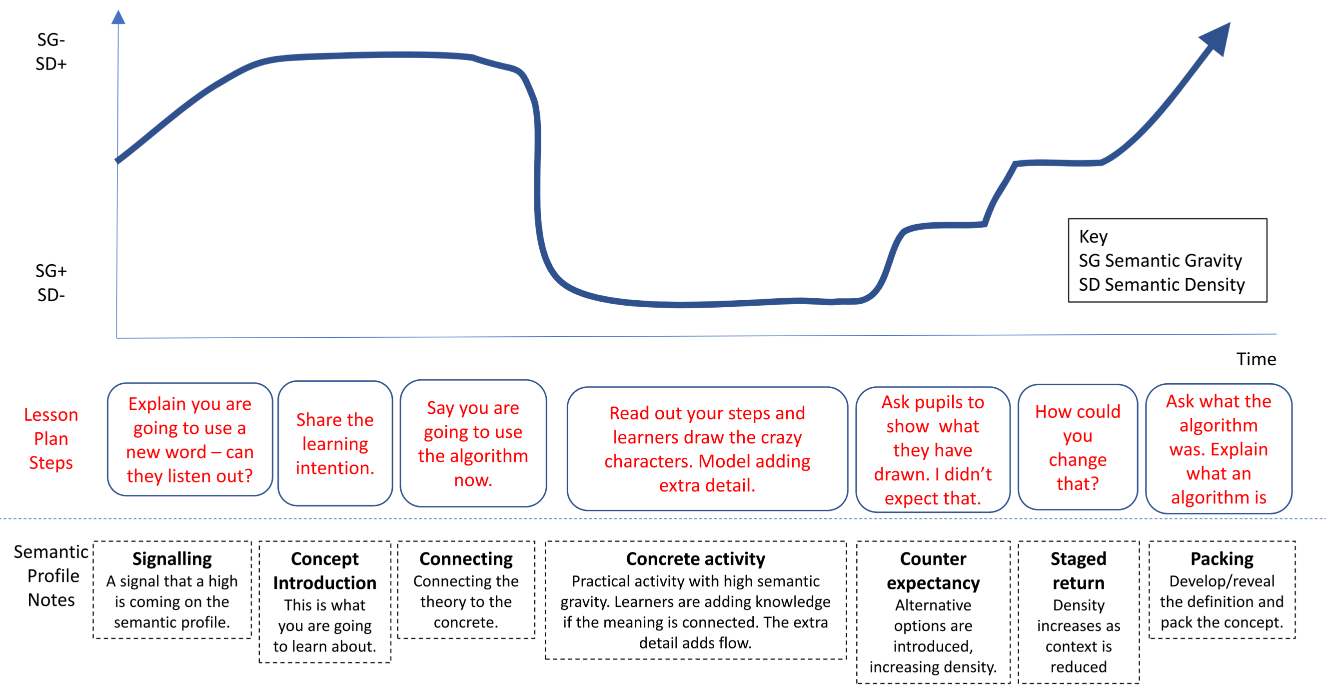

Figure 4: Semantic profile for the Crazy Characters lesson plan introduction.

4.4.5 Counter expectancy. The teacher is instructed to be very vague with the instructions given to learners. The aim is that when she asks the pupils to share their drawings, the image will be very different and she can say that she did not expect this to be the case and ask why. This is called *counter expectancy.* This means that the context in which the learners are developing their understanding is challenged and alternative options are raised. This increases the meaning of the concept. On the semantic profile, this is shown as a staged step up (widening the context weakens semantic gravity; adding meaning strengthens semantic density).

4.4.6 Staged return. Next, the teacher is required to ask the learners how they could improve the algorithm. Learners start to think about making the algorithm more precise but this is still in a relatively specific context. On the graph, this shows as another staged step upwards (adding meaning strengthens semantic density).

4.4.7 Packing. Finally, the plan instructs the teacher to ask a generic question of 'What was the algorithm?' This is a more general view of the activity requiring the learner to 'pack' their accumulated understanding from the practical activity. This is moving up the profile, further away from a specific context and adding more meanings (reducing context-dependence weakens semantic gravity).

4.4.8 The rest of the lesson. We have only profiled the first activity of the full lesson here. Broadly, the rest of the lesson follows a similar set of patterns. However, the highly prescriptive nature of the introduction is loosened as the learners create their own crazy character algorithms. Included in this is the introduction of a further concept, that of debugging, as they ask their friends to implement their algorithms as drawings and then together they debug the algorithm in order to produce the same imagined character.

4.5 Discussion

4.5.1 Outcomes. The experience of drawing the semantic profile for Crazy Characters, applying semantic waves, from theory to practise, led to several useful outcomes. Firstly, it provided a language that helped describe the lesson plan. Secondly, and more importantly, semantic profiling enabled us to analyse the plan in a way that reveals why the learning activity works. It shows how ideas are introduced in a concrete way and more complex meanings are gradually added, step-wise, to develop a more general and abstract understanding. It also shows how specific, apparently small points, of the plan are actually very significant. Thirdly, the process supported the review of the activity helping the reviewer to think of ideas to improve and build upon the lesson plan. Finally, this activity has shown that semantic profiling is a practical and useful approach worthy of further use in Computer Science Education: when creating lesson planning material, when reviewing it, and when designing teacher professional development.

4.5.2 Inclusion and waving. Research by Hasan [2009] suggests that learners from more socially advantaged homes may be more comfortable with *semantic waves* than students from less advantaged homes who may experience less *semantic waving*. The rationale is that some learners are more likely to have generalised and complex meanings explained to them, from a very young age. In other words, the 'why' question gets answered and experiences are provided that exemplify the 'why'. This suggests the use of semantic waves at school from an early age is important.

4.5.3 Potential Changes to Crazy Characters. The review did not suggest a strong need to change the main steps of the Crazy Character lesson plan. Creating the semantic profile, has revealed how the plan provides a carefully scaffolded learning experience to help learners develop an understanding of the meaning of the algorithm concept. As shown in Figure 4, the lesson plan unpacks and then repacks the concepts. It includes a signal that a new concept is to be taught, introduces the concept, connects theory to a concrete activity, incorporates a concrete activity and in a stepwise manner increases the meanings condensed within the concept to finally reveal to the learner a ‘packed’ (complex) definition of the concept.

The notion of semantic waves suggests that building on previously developed waves is important to deliver deeper understanding. To maintain the semantic wave and give a deeper understanding of what an algorithm is, it would be useful to add a follow on lesson which, for the same context, applies what was learned in this unplugged lesson, but in a programming context. Older students will also need to build on the meaning of an algorithm developed here moving in new waves ever higher up the wave to expertise.

Other research suggests explicit introduction of design [Waite et al. 2018] is important in the teaching of programming. This requires the introduction of ‘design’ as a new concept with potentially strong semantic density. A semantic wave needs to be built in to any such activity to unpack and repack this term too, while reinforcing that of the algorithm, and of programming concepts.

4.5.4 A fixed profile? We have analysed the lesson plan as though it is delivered to the letter of the plan, presenting a profile based on that. The actual profile is likely to be different each time it is delivered. Teachers are likely to change how they deliver the lesson, and if so the semantic profile will be different each time they do so. Similarly, different learners engage in an activity in different ways. This will mean that each learner experiences a different personal semantic profile based on their own knowledge building event. However, developing a general semantic profile reveals the strength of the foundation such variations are built upon.

In empirical research it may be useful to develop semantic profiles of lesson resources to enable comparison of the *intended* delivery of a lesson to its *actual* delivery This is particularly pertinent, at this point in time, as there is an urgent call for research in classroom settings to investigate effective pedagogy for teaching computing [The Royal Society 2017].

5 CONCLUSIONS

Computer Science is a very technical subject based on abstract concepts and terminology. The concepts that matter tend to be invisible and intangible, hidden within black boxes. We have argued that effective unplugged activities should follow the pattern of semantic waves. We suggest that semantic profiles also provide a good way to analyse the effectiveness of specific computing lesson plans and in particular unplugged activities.

We applied this to a small unplugged activity case study. Developing the semantic profile for the Crazy Characters activity revealed that it does indeed follow a semantic wave, first unpacking and then repacking the concept of an algorithm for students. This shows how developing a semantic profile can feasibly be used to analyse unplugged activities.

It illustrates, with a concrete example, the way unplugged activities can follow a semantic wave. Crazy Characters is popular with teachers and is believed to be an effective activity. The case study is at least suggestive that this wave structure is part of the explanation of its potential effectiveness.

Semantic profiles may also help reveal why there is such a variability in the effectiveness of unplugged activities in practice. Just because an activity is unplugged does not mean the plan for using it will follow a semantic wave. Similarly, the original activity may have planned a wave, but the facilitator may have broken the wave by not following the steps of the lesson activity. They may not have realised the nuances of each point in the planning [Bell and Lodi 2019], for example. Just because they can follow a semantic wave, in itself does not imply that all unplugged activities and all ways of delivering any particular activity will do so, so will be effective. The particular way they are structured, or used in practice, may not always follow an effective semantic wave. For example, one trap it is easy to fall in to is to leave students at the bottom of the wave. In practice this leaves students understanding only the analogy used, and not how it relates to the intended technical concept. Furthermore, if an unplugged activity does not involve active participation of the students, then the teacher may be following the wave and doing the packing and unpacking themselves. The students meanwhile are just passive observers so may not do any packing or unpacking at all. When activities are used as a demonstration, to explain concepts, it is still important that students actively work with the concepts introduced following their own semantic waves.

6 FURTHER WORK

We have so far developed the semantic profile of a single unplugged activity. It has revealed the potential power of the theory and of this approach to help analyse and so potentially improve computing lesson plans to more effectively involve students in unpacking and repacking concepts. We intend to develop semantic profiles for further unplugged activities, and chained sequences of such activities, both as explanatory devices and whole class activities. Resources from Barefoot [Berry et al. 2019], Teaching London Computing (http://teachinglondoncomputing.org) and csunplugged [Bell et al. 2009] will be reviewed. To explore the usefulness of the tool, it needs to be applied to not only a variety of activities but also to ones with varying degrees of success, to see if it explains their effectiveness. This could be the basis of controlled experiments.

We would like to apply the theory to other kinds of activity, following other pedagogies. Of particular interest is applying the theory to the teaching of programming and computational thinking, developing the transition from novice and expert in terms of semantic gravity and semantic density. This includes exploring how best to combine unplugged and traditional activities in teaching programming. This could lead to empirical investigations investigating whether changes to lesson plans that improve the semantic profile do lead to more effective computer science lessons. Further work is needed to develop and trial the approach for use by teachers and resource developers. We will explore how Semantic Waves are can be successfully used in computing classrooms.

7 ACKNOWLEDGMENTS

This work was supported by the Institute of Coding, which is supported by the Office for Students (OfS). We are grateful to James Donohue for introducing us to LCT at QMUL.

REFERENCES

L.W. Barsalou, P.M. Niedenthal, A.K. Barbey, and J.A. Ruppert. 2003. Social embodiment. *Psychology of learning and motivation* 43 (2003), 43–92.

T. Bell, J. Alexander, I. Freeman, and M. Grimley. 2009. Computer Science unplugged: school students doing real computing without computers. *The New Zealand Journal of Applied Computing and Information Technology* 13, 1 (2009), 20–29.

T. Bell and M. Lodi. 2019. Constructing computational thinking without using computers. *Constructivist Foundations* 14, 3 (2019). https://constructivist.info/14/3 In press.

M. Berry, J. Woolard, J. Chippendahal, Z. Ross, and J. Waite. 2019. Barefoot Computing. (2019). Retrieved June 12, 2019 from https://www.barefootcomputing.org/

M.A.L. Blackie. 2014. Creating semantic waves: using Legitimation Code Theory as a tool to aid the teaching of chemistry. *Chemistry Education Research and Practice* 15, 462 (2014).

P. Curzon and P.W. McOwan. 2008. Engaging with Computer Science through magic shows. *ACM SIGCSE Bulletin* 40, 3 (2008), 179–183. Also in Proceedings of ITiCSE 2008.

P. Curzon, P.W. McOwan, Q. Cutts, and T. Bell. 2009. Enthusing and inspiring with reusable kinaesthetic activities. *ACM SIGCSE Bulletin* 41, 3 (2009), 94–98.

P. Curzon, P.W. McOwan, J. Donohue, S. Wright, and D.W. Marsh. 2018. Teaching Computer Science concepts. In *Computer Science Education: Perspectives on Teaching and Learning in School*, S. Sentance, E. Barendsen, and C. Schulte (Eds.). Bloomsbury Publishing, London, Chapter 8, 91–108.

R. Hasan. 2009. *Semantic variation.* Equinox, London.

legitimationcodetheory.com. 2019. Legitimation Code Theory. (2019). Retrieved June 13, 2019 from http://legitimationcodetheory.com/

D. Love. 2016. *Any tool works if you are using the language: The role of knowledge in ICT integration in a Johannesburg private school.* Master's thesis. School of Education, University of the Witwatersrand, Johannesburg, South Africa. Retrieved July 27, 2019 from http://wiredspace.wits.ac.za/handle/10539/22614

L. Macnaught, K. Maton, J.R. Martin, and E. Matruglio. 2013. Jointly constructing semantic waves: implications for teacher training. *Linguistics and Education* 24, 50-63 (2013). https://doi.org/10.1016/j.linged.2012.11.008

K. Maton. 2013. Making semantic waves: a key to cumulative knowledge-building. *Linguistics and Education* 24, 8-22 (2013).

K. Maton. 2014. *Knowledge and Knowers: Towards a realist sociology of education.* Routledge, Milton Park, Abingdon, Oxon.

K. Maton, S. Hood, and S. Shay. 2016. *Knowledge-building : educational studies in legitimation code theory.* Routledge, New York.

S.B. Merriam. 2009. *Qualitative Research: A Guide to Design and Implementation.* John Wiley & Sons, San Francisco, CA.

S. Papert and I. Harel. 1991. *Constructionism.* Ablex Publishing, New York.

J. Piaget. 1971. *Psychology and Epistemology: towards a theory of knowledge.* Grossman, New York.

B. Rodriguez, S. Kennicutt, C. Rader, and T. Camp. 2017. Assessing computational thinking in CS Unplugged Activities. In *Proceedings 2017 ACM SIGCSE Technical Symposium on Computer Science Education.* ACM, New York, 501–506.

R.E. Stake. 1995. *The art of case study research.* Sage, Thousand Oaks, CA ; London.

The Royal Society. 2017. After the reboot: Computing education in UK schools. (2017). Retrieved July 24, 2019 from https://royalsociety.org/topics-policy/projects/computing-education/

R. Thies and J. Vahrenhold. 2016. Back to school: Computer Science unplugged in the wild. In *Proceedings 2016 ACM Conference on Innovation and Technology in Computer Science Education.* ACM, New York, 118–123.

J. Waite. 2017. Pedagogy in teaching Computer Science in schools: a literature review (After The Reboot: computing education in UK Schools). Online. (November 2017). Retrieved July 24, 2019 from https://royalsociety.org/-/media/policy/projects/computing-education/literature-review-pedagogy-in-teaching.pdf

J. Waite, P. Curzon, D. Marsh, S. Sentance, and A. Hawden-Bennett. 2018. Abstraction in action: K-5 teachers' uses of levels of abstraction, particularly the design level, in teaching programming. *International Journal Of Computer Science Education In Schools* 2, 1 (2018). https://doi.org/10.21585/ijcses.v2i1.23