Design & Technology and Computer Science in the CAMAU Project: The Genesis of Learning Progression in the New Curriculum for Wales

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Abstract

Wales is currently undertaking significant curricular reform following a systematic review of the country's education system (Donaldson, 2015). As frameworks that reflect evolving societal demands and shape learning experiences, curricula occupy a powerful and integral place in Education. Despite this, it is not always clear that they support pupils' learning in ways that pay attention to research evidence and classroom experience.

The CAMAU Project (University of Glasgow & University of Wales Trinity Saint David), designed to address this concern, was commissioned by the Welsh Government to support the process of radical, evidence-based curricular reform. Developed around the Integrity Model of Change (Hayward & Spencer, 2010), it brings together researchers, policy-makers and Welsh teachers as co-developers of learning progressions using participatory research methods (Bergold & Thomas, 2012) and the principle of subsidiarity (Donaldson, *ibid*). These frameworks will support planning and formative assessment by describing learning journeys for Welsh pupils aged 3 to 16.

This paper describes the CAMAU project and discusses selected findings from research, policy and practice in the first phase of developing progression frameworks for Design and Technology, and Computer Science. Reviews of research and policy presented in Hayward et al (2018) were undertaken using the 'Knowledge to Action' method (Khangura et al, 2012). A discussion of this evidence suggests that ideas of 'the process of abstraction', 'systems and mental models' and 'quantity, level of integration and complexity of factors considered' may be important in learning progression. From the perspective of practice, more open-ended pupil tasks appear to support teachers better in the early stages of thinking through progression. When initially describing learning progression, many teachers focused on describing particular task requirements or the independent use of skills, rather than the underlying conceptual understanding. Initial descriptions were more skill-based with less agreement about the knowledge required to support progression.

Keywords: Learning Progression, Design & Technology, Computing Science, Curriculum for Wales, Research, Policy and Practice, CAMAU Project.

Introduction

While it can be safely assumed that representations of progression have always featured in the curricula of formal education, recent interest points to a growing critical recognition of the importance of progressions for learning and teaching. Heritage (2008), for example, observes that statements of curricular standards often do not provide a clear picture of learning progression. She argues that, were this to be addressed, teachers could gain greater clarity about how learning progresses in particular domains and engage in more effective formative assessment. Similar concerns are raised by Black et al (2011) who argue for 'evidence-based road maps' of the journey through which learning would typically move in order to support classroom pedagogy and assessment. Many examples of such approaches can be found for

Science Education, often framed around ‘big ideas’ (Harlen, 2010) and provide structures for refining curricula in ways that can deepen our understanding of what is truly important for future learning.
There are some indications that areas of Technology Education may be starting to explore this type of thinking. In the United States, the National Research Council have identified nine big ideas for engineering organised by knowledge, skills and habits of mind (NCR, 2009). More recently in the United Kingdom, Barlex & Steeg (2017), propose big ideas ‘about’ the fundamental nature of design and technology and big ideas ‘of’ design and technology including materials, manufacture, functionality, design, and critique. Similar work in New Zealand has been undertaken by Bell, Tymann and Yehudai (2018) to identify ten big ideas for K12 Computer Science curricula. Despite such efforts to key into what matters, associated evidence about how learning progresses in Design & Technology (D&T) and Computer Science (CS) remains sporadic and limited in comparison to Science (Hayward et al, 2018). Given the concerns of Heritage (2008) and others, this calls into question the extent to which representations of progression in our existing curricula are truly evidenced-based.

Learning progression is complex and it can be conceptualised and explored in a range of ways (Lobato & Walters, 2017). A pedagogical or curricular teaching sequence, for example, may not necessarily reflect increasing sophistication in pupil learning. More broadly, studies that explore and seek to understand learning do not necessarily contribute readily to understanding what more complex learning looks like in different areas of learning. The CAMAU Project (Welsh for ‘Steps’) is a 3-year project commissioned by the Welsh Government that places learning progression at the heart of the new curriculum for Wales. Around 120 teachers, 20 policy leads and 20 researchers participated in this project over an extended period. Through the co-construction of evidence-informed progression frameworks for all six ‘areas of learning and experience’ (AoLEs) in the new Curriculum for Wales (Donaldson, 2015), the project seeks to develop and share understanding of how curriculum, progression and assessment might be described and enacted in Wales to focus upon learning through better alignment between research, policy and practice.

This paper reports upon the first phase of developing progression frameworks for D&T and CS as part of the work undertaken in the Science & Technology AoLE. Firstly, it describes the work of the CAMAU Project in the context of Welsh educational reform, the socio-cultural grounding adopted, and the methods developed to support the authentic co-construction of a national, learning-centred curriculum. Secondly, it uses a framework of selected findings from the summaries of research and policy presented in the recent CAMAU Research Report (‘Learning About Progression’, Hayward et al, 2018) to explore evidence from teachers’ early thinking through of progression for aspects of D&T and CS. The paper concludes by drawing together implications.

The Context and Starting Point for the CAMAU Project

There are international, national and developmental features to the context of the CAMAU work on learning progression. The Welsh education system is currently undergoing significant systemic change initiated through Welsh Government concern about a perceived fall in educational standards (Estyn 2014, HMCI Wales 2012, Welsh Government 2012), evidenced by weak performance in international PISA tests (Wheater et al. 2013). A review of the National Curriculum (Donaldson 2015) resulted in recommendations on the design of a new, purpose driven curriculum which have been accepted in full by the Welsh Government (2015). With respect to the CAMAU Project, key recommendations pertained to curricular organisation, progression and subsidiarity:

- A curriculum organisation into six areas of learning and experience (Languages, Literacy & Communication, Maths & Numeracy, Expressive Arts, Health & Well-Being, Science & Technology and Humanities).
- A move away from key stage standards towards progression steps. These steps are comprised of achievement outcomes that support forward-facing formative assessment and progression rather than provide backward-facing summaries (Donaldson, 2015:114).
- Adherence to the principle of 'subsidiarity', which is defined as "commanding the confidence of all, while encouraging appropriate ownership and decision making by those closest to the teaching and learning process" (Donaldson, 2015, p.14). In contrast to more top-down approaches (Kelly, 2009), this places teachers at the heart of developing the Curriculum for Wales with the Welsh Government identifying and funding around 70 schools with particular expertise to participate.

The Science & Technology AoLE brings together aspects of learning traditionally defined in subjects such as Physics, Chemistry, Biology, Design & Technology and Computer Science. Notably, it is the first time that aspects of CS have been recognised as a core area in the Welsh Curriculum across the ages of 3-16. This AoLE not only fosters a rich and diverse learning space in the curriculum, it provides opportunities to think through the interrelationships between learning in different areas. Though some levels of distinction were ultimately retained, early and significant thinking in this AoLE considered whether these areas could or should be more fully integrated.

In the year prior to the start of the CAMAU Project, the Science & Technology AoLE also developed descriptions of 'What Matters' for learning. What matters align with the curriculum purposes and can be understood as those things that are most important for an educated Welsh citizen to know, understand and be able to do by the age of 16. What Matters for Science & Technology was initially set out in eight statements and rationales providing a series of starting points for the development of progression frameworks in the CAMAU Project. Over time, the iterative development process merged societal and environmental impacts of science and technology across the other areas and design thinking and engineering were combined which resulted in six what matters statements. Two were related to Design and Technology and Computer Science which are:

WM 2 Design thinking and engineering are technical and creative endeavours intended to meet society's needs and wants
WM 6 Computation applies algorithms to data in order to solve real-world problems

The Theoretical Grounding of the CAMAU Project

The CAMAU Project was designed to support a complex process of collaborative development involving researchers, policy makers and teachers in the context of large-scale systemic change. It is concerned not only with the development of progression frameworks, but also the nature of the collaborative processes from which these emerged. Fundamentally, the project is grounded upon socio-cultural theories of understanding (Rosa & Montero, 1990; John-Steiner & Mahn, 1996) and the principle of subsidiarity (OECD, 2017; Donaldson, 2015). This shaped activity at all levels of the project including the longitudinal work undertaken within Science & Technology. From this stance, the evidence and expertise brought to bear in creating learning progressions is mediated and developed through the sustained and culturally situated social interactions of the participating researchers, policy makers and teachers. It is through these interactions that understandings of learning progression collectively emerge. Towards this end, the integrity model of change (Hayward et al, 2010) was adopted to frame ways of exploring the nature of change processes in the development of progression frameworks for Wales. This model suggests that sustainable change requires that educational, personal and professional, and systemic integrity are maintained and appropriately aligned throughout (Hayward et al, ibid).

AoLE Participants & Overall Project Design

The Science & Technology AoLE consisted of 2 policy leads, 3 researchers and around 20 teachers, who met monthly. This varied sometimes in response to the changing nature of tasks and, over time, involved several external subject experts. The CAMAU Project is designed around three large-scale iterative activity phases. Phase 1 gathered evidence about learning progression in relevant subject areas from research, international policy and practice for each of the AoLEs. In Science & Technology, this allowed a shared understanding of progression in areas such as energy, designing and making, and algorithms to develop among researchers, teachers and AoLE policy leads. Critically, it provided a basis from which progression frameworks could be collaboratively developed in phase 2. Phase 3 will gather and analyse empirical evidence to support the iterative refinement of progression frameworks and the wider implementation of the curriculum across Wales. As previously stated, this paper discusses findings for D&T and CS from Phase 1.

Methodology

Two main methodologies were developed to gather evidence for D&T and CS in Phase 1. Reviews of research and international curricular policy were undertaken and a participatory activity was developed to explore teachers' initial conceptions in thinking through learning progression.

To produce a dependable summary of evidence for D&T and CS (Grant & Booth, 2009), research and policy reviews were carried out using the 'Knowledge to Action' method described by Khangura et al, (2012). This eight-stage approach used is described in Hayward et al (2018) and involved identifying, screening, analysing and summarising research and several national curricular frameworks using guiding questions about how progression was conceptualised and represented. The identification and screening process revealed that despite large numbers of studies providing insights into aspects of learning in D&T and CS, relatively few considered the way in which learning changes over time. The research and policy reviews were supported by six Professorial Consultants and by the project's National and International Advisory Group. Summaries of the findings from this process, presented in Hayward et al (2018), are discussed in the following section of this paper.

To elicit provisional evidence and build knowledge about teachers' existing conceptions of learning progression in their subject areas, a four-stage participatory research task was designed (Bergold & Thomas, 2012). Small groups of teachers with a shared subject interest were established. As far as possible, each group comprised three or four teachers from both primary and secondary settings. In the first stage, each group critically reviewed a range of possible investigative methodologies and either selected the one they considered most appropriate or developed their own with support from researchers. In the second stage, teachers identified examples of pupil classroom work that covered a range of knowledge, concepts and skills that they thought were important. Given that the mental models of how learners understanding develops held by teachers are often fragile, incomplete and challenging to make explicit (Carpenter, et. al, 1988; Fennema, et. al. 1996), real classroom work served as a culturally aligned mediating artefact in the process of thinking through progression. The third stage involved comparative analysis of this pupil work by the teachers, scaffolded using stimulus questions. During the final stage, teachers ordered and summarised the successively more complex shifts in learning they had identified. All three groups featured in this paper (CS, n=2, D&T, n=1) were asked to compare pupils' work at three different stages of a learning journey. Rather than seeking to establish actual learning progressions, this activity gave insight into teachers' initial conceptualisations of learning shifts to support the work in phases 2 and 3 of the CAMAU project. Staged task outputs, summaries of teacher discussions, agendas and observational reflections provided evidence for this process.

Phase 1: Discussion of Ideas from Research and Policy

The summaries of research and policy evidence of learning progression in D&T and CS from Phase 1 are presented in Hayward et al (2018). The discussion presented here highlights preliminary findings from on-going work that will be discussed more fully in subsequent publications.

For each of these subject areas, there were few studies reviewed with a primary focus upon learning progression or trajectories (e.g. Kimbell, 1994; Compton & Harwood, 2003; Compton & Harwood, 2005; McLaren & Stables, 2008; Jones, 2009; Danos & Norman, 2011; Seiter & Foreman, 2013; Rich et al, 2017). The most significant empirical basis was found across the work of Compton, Compton and Harwood which, at the time, supported reforms to the New Zealand curriculum. Other studies, such as those comparing novice/less developed and expert/more developed learning (e.g. Teague, 2015; Morrison-Love, 2015) or approaches to deeper learning (Grover et al, 2015; Bocconi et al, 2016), contribute to parts of the developing picture of learning progression in both D&T and CS. More recent studies of this type are beginning to shed light on factors that support greater success in different forms of learning (e.g. Bartholomew & Strimel, 2018; Rich et al, 2018; Wong & Jiang, 2018; Rich et al, 2019). Some studies from the learning sciences similarly provide insights into aspects of CS such as learning to program (e.g. Wyeth, 2008). Variations in the types of studies reviewed make structured cross-comparison challenging. However, attention can be usefully drawn to ideas of 'the process of abstraction', 'systems and mental models' and 'quantity, level of integration and complexity of factors considered' that appear in ideas of progression for both D&T and CS.

The process of abstraction in those studies reviewed can be seen to involve learner and different system/artefact representations, and some form of transactional process. In computational thinking, this can involve learners establishing patterns and levels of interaction between computers and users (Colburn & Shute, 2007; Hill et al, 2008) or between abstract concepts and how they are implemented in a specific digital system or application (Connor et al, 2017). Understanding similar interactions in developing technical solutions is likely also to be important for learning in D&T. Particularly for ideation, sketching/modelling and testing, pupils' ability to utilise different degrees and forms of abstraction in ways that foster a more expert and connected understanding is important (e.g. Mioduser et al, 2007; Haupt, 2018). Unlike areas of maths and science that tend to proceed from more concrete experiences to abstract ideas, the role of abstraction may be more varied in moving towards sophisticated forms of understanding in technology. For example, the development of solutions often involves the generation of abstract ideas and designs that gradually become more detailed as they move towards their final concrete physical or digital forms (Morrison-Love, 2017). Examples of shifts that involve different uses of abstraction can also be identified in curricular policy (Table 1).

Aspect	Design and Technology	Computer Science
Development of Solutions	Develop a simple sketch, drawing, or physical model to illustrate how the shape of an object helps it function as needed to solve a given problem. Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved. Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved. *United States Engineering Design Next Generation Science Standards K2, K3-5 and Middle School*	People develop programs collaboratively and for a purpose, such as expressing ideas or addressing problems. People develop programs using an iterative process involving design, implementation and review. Design often involves reusing existing code or remixing other programs within a community. People design meaningful solutions for others by defining a problem's criteria and constraints, carefully considering the diverse needs and wants of the community and testing whether the criteria and constraints were met. *United States K12 Computer Science Framework Program Development Progression Grade 2, 5 and 8.*

Table 1: Progression in Curricular Policy Involving Working Abstraction

It is also proposed in CS, that more sophisticated learning depends upon pupils developing an appropriate mental model of the computer as a 'notional machine' (Du Boulay, 1986; Ben-Ari, 2001; Sorva, 2013). Moreover, it is suggested that this is supported better by knowledge at the level of structure and actions than it is by lower level knowledge of, for example, bit manipulation. Arguably a form of systems model, this is important for developing reasoning. Whilst the notional machine in CS develops around largely fixed parameters and affordances, more sophisticated reasoning about differing technical artefacts and outcomes in D&T also requires a sufficiently developed mental model (see: 'Analytical Reflection' in Morrison-Love, 2015). Similarly, such mental models often encompass knowledge about structure and action in technical solutions and foster a more technical understanding of how things work, rather than a scientific understanding of why things work (Banks & Plant, 2013). Examples of progression from curricula involving this type of understanding are shown in Table 2.

Aspect	Design and Technology	Computer Science
Physical and Digital Systems	explore and use mechanisms [for example, levers, sliders, wheels and axles], in their products. understand and use mechanical systems in their products [for example, gears, pulleys, cams, levers and linkages] understand how more advanced mechanical systems used in their	Demonstrates an understanding that computers take information as input, process and store that information and output the results. Describes the purpose of the processor, memory and storage and the relationship between them. Demonstrates an understanding of the von Neumann architecture and

	products enable changes in movement and force. *English Design and Technology National Curriculum Key Stage 1, 2 and 3*	how machine code instructions are stored and executed within a computer system. *Scottish Technologies Computing Science Curriculum Organiser 1st, 2nd and 3rd level Benchmarks*

Table 2: Progression in Curricular Policy Involving Mental Models

Research evidence in both D&T and CS reveals something of the quantity, level of integration and complexity of factors considered in more sophisticated learning. In designing technical and coding solutions, pupils appear able to actively integrate or 'operationalise' a greater number of different types of factors at more developed stages of learning (Jones, 2009; McLaren & Stables, 2008; Morrison-Love, 2015; Aivaloglou et al., 2017; Franklin et al., 2017). Moreover, they are increasingly able to evaluate these against particular conditions, constraints and affordances. These shifts are reflected to some extent in examples of curricular policy (Table 3).

Aspect	**Design and Technology**	**Computer Science**
Evaluation of Design	… evaluate ideas and designed solutions against identified criteria for success, including environmental sustainability considerations. They suggest criteria for success, including sustainability considerations and use these to evaluate their ideas and designed solutions. They develop criteria for success, including sustainability considerations, and use these to judge the suitability of their ideas and designed solutions and processes. *Australian Curriculum Design and Technology Sequence of Achievement from Years 3 and 4, 5 and 6 and 7 and 8*	They also evaluate user interfaces in relation to their efficiency and usability. .. they develop programs considering human-computer interaction (HCI) heuristics. They apply design principles and usability heuristics to their own designs and evaluate user interfaces in terms of them. *New Zealand Computational Thinking for Digital Technologies Progression* *Progress Outcomes 4, 5 and 6*

Table 3: Progression in Curricular Policy Involving Quantity, Level of Integration & Complexity

Phase 1: Selected Insights from Practice

The first group examined a small sample of different pupil work that lacked variation within particular task outcomes to support them in thinking about progression in CS. After some initial difficulties selecting work to examine and discuss, they mainly focused on the relative difficulty of different programming related tasks. Although descriptions produced were limited and high-level there was some indication that the variety and complexity of programming constructs used was a key discriminator between novices at different stages of development. The second group thinking about progression in IT using work from a single tightly scaffolded multimedia development task and focused upon identifying skills pupils could successfully carry out independently at two points in time rather than how learning had shifted. In thinking through progression at the beginning of phase 1 both Computing groups found it a challenge to focus on describing shifts in learning, focusing respectively on either task completion or skills independently used by learners.

By contrast, the D&T group analysed a more open-ended mascot design task completed by pupils at a range of ages and stages and were quickly able to focus on describing learning progression. The statements generated were more numerous and finer grained and there was clear evidence of describing progression in the ability to consider and integrate a gradually more complex set of design and technology factors over time. These included moving from focusing on just the visual appearance of an idea to considering factors such as scale, dimension and materials and techniques that would aid in the process of constructing the mascot. There was also some evidence of consideration of abstraction with the learning progression indicating an expectation that novices would increasingly reduce the level of abstraction in their design idea to increasingly include details of how it could be implemented in a concrete physical form in the construction phase.

The Computing and D&T groups experiences suggests that examining pupil work generated by several closed or tightly scaffolded tasks may offer less discrimination between stages of learning than a single open-ended task with minimal teacher scaffolding carried out across a range of age groups. This echoes the approach to generating evidence of levels of achievement employed in Technology by the New Zealand National Education Monitoring Project (2008); suggesting analysis of a range of samples of work and/or pupil performance in open-ended tasks is also beneficial for developing teachers understanding of progression in learning.

Feedback from both the AoLE leads and members indicated that they valued the exercise and suggested a future role for it to help support a shift in other teachers understanding from an assessment standard driven to a progression orientated view of learning and teaching.

Conclusions & Implications

This paper described the work of the CAMAU Project and provided insights from evidence in research, policy and practice from the first stages of understanding and thinking through progression for D&T and CS. Some aspects such as the process of abstraction, systems and mental models and factors, integration and complexity appear to play role in each area, but there remains a need to understand better the nature of and approaches to developing teachers understanding of learning progression. Not only will this further support classroom learning and formative assessment, but it offers new and significant potential for how we understand and conceptualise D&T and CS as important areas of learning going forward.

References

Australian Curriculum, Assessment and Reporting Authority (ACARA). (2016). Technologies: Sequence of Achievement. Retrieved from http://docs.acara.edu.au/resources/Technologies_Sequence_of_achievement.pdf

Aivaloglou, E., Hermans, F., Moreno-León, J. & Robles, G. (2017). A Dataset of Scratch Programs: Scraped, Shaped and Scored. In *Proceedings of the 14th International Conference on Mining Software Repositories,* MSR '17 (pp. 511-514). Piscataway, NJ: IEEE Press.

Banks, F., Plant, M. (2013). Transferring Knowledge Versus Knowledge Through Technology Education. In Middleton, H. E. & Baartman, L. K. J. (Eds.), *Transfer, Transitions and Transformations of Learning.* Springer (pp. 23–37), Rotterdam, Netherlands: Sense Publishers.

Barlex, D. & Steeg, T. (2017). Big Ideas in Design & Technology: A Working Paper. Retrieved from https://dandtfordandt.files.wordpress.com/2017/05/big-ideas1.pdf

Bartholomew, S.R., Strimel, G.J. and Yoshikawa, E. (2018). Using Adaptive Comparative Judgment for Student Formative Feedback and Learning During a Middle School Design Project. *International Journal of Technology and Design Education*, *29(2),* 1-23. https://doi.org/10.1007/s10798-018-9442-7

Bell, T., Tymann, P. and Yehudai, A. (2018). The Big Ideas in Computing Science for K-12 Curricula. European Association for Theoretical Computer Science. No. 124. Retrieved from http://bulletin.eatcs.org/index.php/beatcs/article/view/521

Ben-Ari, M. (2001). Constructivism in Computer Science Education. *Journal of Computers in Mathematics and Science Teaching*, *20(1),* 45-73.

Bergold, J. and Thomas, S. (2012). Participatory research methods: A methodological approach in motion. *Forum: Qualitative Social Research, 13(1),* 191-222.

Black, P., Wilson, M. and Yao, S.Y. (2011). Road maps for learning: A guide to the navigation of learning progressions. *Measurement: Interdisciplinary Research & Perspective, 9(2-3),* 71-123. https://doi.org/10.1080/15366367.2011.591654

Bocconi, S., Chioccariello, A., Dettori, G., Ferrari, A., Engelhardt, K., Kampylis, P., & Punie, Y. (2016). Developing Computational Thinking in Compulsory Education: Implications for Policy and Practice. JRC Science for Policy Report. European Commission. Retrieved from http://publications.jrc.ec.europa.eu/repository/bitstream/JRC104188/jrc104188_computhinkreport.pdf

Carpenter, T., Fennema, E., Peterson, P., & Carey, D. (1988). Teachers' Pedagogical Content Knowledge of Students' Problem Solving in Elementary Arithmetic. *Journal for Research in Mathematics Education, 19*(5), 385-401. doi:10.2307/749173

Colburn, T., & Shute, G. (2007). Abstraction in computer science. *Minds and Machines: Journal for Artificial Intelligence, Philosophy and Cognitive Science, 17*(2), 169-184. http://dx.doi.org/10.1007/s11023-007-9061-7

Compton, V. & Harwood, C. (2003). Enhancing Technological Practice: An Assessment Framework for Technology Education in New Zealand. *International Journal of Technology and Design Education, 13(1),* 1-26. https://doi.org/10.1023/B:ITDE.0000039567.67842.c3

Compton, V. & Harwood, C. (2005). Progression in Technology Education in New Zealand: Components of Practice as a Way Forward. *International Journal of Technology and Design Education, 15(3),* 253-287. https://doi.org/10.1007/s10798-004-5401-6

Connor, R., Cutts, Q. and Robertson, J. (2017). Keeping the Machinery in Computing Education. *Communications of the ACM, 60(11),* pp.26-28. Retrieved from https://cacm.acm.org/magazines/2017/11/222181-keeping-the-machinery-in-computing-education/fulltext

Danos, X. and Norman, E.W.L. (2011). Continuity and Progression in Graphicacy. In Norman, E.W.L. & Seery, N, (Eds.), *IDATER Online Conference: Graphicacy and Modelling 2010* (pp. 103-119). Loughborough: Design Education Research Group, Loughborough Design School. Retrieved from https://dspace.lboro.ac.uk/dspace-jspui/bitstream/2134/9023/1/Norman-ch-5-IDATER_Online_BOOK%5B1%5D.pdf

Donaldson G. (2015). Successful Futures: Independent Review of Curriculum and Assessment Arrangements in Wales. Welsh Government: Cardiff. Retrieved from https://gweddill.gov.wales/docs/dcells/publications/150225-successful-futures-en.pdf

Du Boulay, B. (1986). Some Difficulties of Learning to Program. *Journal of Educational Computing Research, 2(1),* 57-73. https://doi.org/10.2190/3LFX-9RRF-67T8-UVK9

Estyn. (2014) The Annual Report of HM Chief Inspector of Education and Training in Wales 2013-2014. Retrieved from http://www.assembly.wales/laid%20documents/gen-ld10093%20-%20the%20annual%20report%20of%20her%20majestys%20chief%20inspector%20of%20education%20and%20training%20in%20wales%202013-2014/gen-ld10093-e.pdf

Franklin, D., Skifstad, G., Rolock, R., Mehrotra, I., Ding, V., Hansen, A., ... Harlow, D. (2017). Using Upper-Elementary Student Performance to Understand Conceptual Sequencing in a Blocks-based Curriculum SIGCSE. *Proceedings of the 2017 ACM SIGCSE Technical Symposium on Computer Science Education,* 231-236. doid=3017680.3017760

Fennema, E., Carpenter, T. P., Franke, M. L., Levi, L., Jacobs, V. R. & Empson, S. B. (1996). A Longitudinal Study of Learning to use Children's Thinking in Mathematics Instruction. *Journal for Research in Mathematics Education, 27(4),* 403-434.

Grant, M. J., Booth, A. (2009). A Typology of Reviews: An Analysis of 14 Review Types and Associated Methodologies: Health Information & Libraries Journal, 26(2), 91–108. doi: 10.1111/j.1471-1842.2009.00848.x.

Grover, S., Pea. R., & Cooper, S. (2015) Designing for deeper learning in a blended computer science course for middle school students, Computer Science Education, 25(2), 199-237, DOI: 10.1080/08993408.2015.1033142

Harlen, W., (2018). *The Teaching of Science in Primary Schools* (7th ed.) London, New York: Routledge.

Hayward, L. & Spencer, E. (2010). The Complexities of Change: Formative Assessment in Scotland. *Curriculum Journal, 21(2),* 161-177. https://doi.org/10.1080/09585176.2010.480827

Haupt, G. (2018). Hierarchical Thinking: A Cognitive Tool for Guiding Coherent Decision Making in Design Problem Solving. *International Journal of Technology and Design Education, 28(1),* 207–237. https://doi.org/10.1007/s10798-016-9381-0

Hayward, L., Jones, D. E., Waters, J., Maraka, M., Morrison-Love, D., Spencer, E., … Wardle, G. (2018). CAMAU Project: Research Report (April 2018). Project Report. University of Glasgow, Glasgow. Retrieved from https://www.gla.ac.uk/media/media_587517_en.pdf

Heritage, M. (2008). Learning progressions: Supporting instruction and formative assessment. Council of Chief State School Officers (CCSSO). Retrieved from http://www.k12.wa.us/assessment/ClassroomAssessmentIntegration/pubdocs/FASTLearningProgressions.pdf

Higgins, S., Hayward, L., Livingston, K., & Wyse, D. (2017). A Curricular Lens on Equity and Inclusion: Using Bernstein to Articulate 'Supercomplexity'. *The Curriculum Journal, 28(3),* 303–304. https://doi.org/10.1080/09585176.2017.1341106

Higgins, S., Hayward, L., Livingston, K., & Wyse, D. (2016). Knowledge and the Curriculum: A Recurring Issue. *The Curriculum Journal, 27(4),* 427–429. https://doi.org/10.1080/09585176.2016.1244330

Hill, C. (2014). Computational Thinking Curriculum Development for Upper Elementary School Classes. *Proceedings of the Tenth Annual Conference on International Computing Education Research* (pp.151–152), ICER '14. New York, USA: ACM. Retrieved from https://dl.acm.org/citation.cfm?id=2632327

HMCI Wales (2012). *The Annual Report of Her Majesty's Chief Inspector of Education and Training in Wales 2011-12,* Cardiff: Estyn. Retrieved from http://www.assembly.wales/Laid%20Documents/GEN-LD9253%20-%20The%20Annual%20Report%20of%20Her%20Majesty%E2%80%99s%20Chief%20Inspector%20of%20Education%20and%20Training%20in%20Wales%202011-2012-12032013-243903/gen-ld9253-e-English.pdf

John-Steiner, & V., Mahn, H., (1996). Sociocultural Approaches to Learning and Development: A Vygotskian Framework. *Educational Psychologist, 31(3-4),* 191–206.

Jones, A. (2009). Towards an Articulation of Students Making Progress in Learning Technological Concepts and Processes. In Jones, A. & de Vries, M. (Eds.). *International Handbook of Research and Development in Technology Education, International Technology Education Studies.* Sense Publishers (pp. 407-417). Rotterdam, Netherlands.

K-12 Computer Science Framework Steering Committee. (2016). K-12 Computer Science Framework Statements by Progression. Retrieved from https://k12cs.org/framework-statements-by-progression/

Kelly, A.V. (2009). The Curriculum, Theory and Practice (6th ed.). London: SAGE Publications Ltd.

Kimbell, R. (1994). Progression in Learning and the Assessment of Children's Attainments in Technology. *International Journal of Technology and Design Education, 4(1),* 65-83. https://doi.org/10.1007/BF01197584

Khangura, S., Konnyu, K., Cushman, R., Grimshaw, J. & Moher, D. (2012). Evidence Summaries: The Evolution of a Rapid Review Approach. *Systematic Reviews, 1(10),* 1-9. doi:10.1186/2046-4053-1-10

Lobato, J. & Walters, C. D. (2017). A Taxonomy of Approaches to Learning Trajectories and Progressions. Compendium for Research in Mathematics Education. Reston, VA: National Council of Teachers of Mathematics.

McLaren, S. V. and Stables, K. (2008). Exploring key Discriminators of Progression: Relationships between Attitude, Meta-Cognition and Performance of Novice Designers at a time of Transition. *Design Studies, 29(2),* 181-201.

Mioduser, D., Levy, S. T., Talis, V. (2009). Episodes to Scripts to Rules: Concrete-Abstractions in Kindergarten Children's Explanations of a Robot's Behavior. *International Journal of Technology and Design Education 19(1),* 15-36.

Morrison-Love, D. (2015). Technological Problem Solving as Skills for Competitive Advantage: An Investigation of Factors Associated with Levels of Pupil Success. In *11th International Conference on Technology Education in the Asia-Pacific Region.* Hong Kong Polytechnic University: Hong Kong.

Morrison-Love, D. (2017). Towards a Transformative Epistemology of Technology Education. *Journal of Philosophy of Education, 51(1),* 23-37. doi:10.1111/1467-9752.12226

National Education and Monitoring Project (NEMP). (2008). *2008 Technology Assessment Results.* National Education and Monitoring Report 48.

National Research Council (NRC). (2009). *Engineering in K–12 Education: Understanding the Status and Improving the Prospects.* Washington, DC: National Academies Press. Retrieved from https://www.nap.edu/catalog/12635/engineering-in-k-12-education-understanding-the-status-and-improving

OECD. (2017). Education at a glance. Retrieved from http://www.oecd.org/education/educationataglance2017-countrynotes.htm

Rich, K. M., Strickland, C., Binkowski, T. A., Moran, C. and Franklin, D. (2017). K-8 Learning Trajectories Derived from Research Literature: Sequence, Repetition, Conditionals. In *Proceedings of the 2017 ACM Conference on International Computing Education Research* (pp. 182-190), Washington, USA: ACM.

Rich, K. M., Binkowski, T. A., Strickland, C. and Franklin, D. (2018). Decomposition: A K-8 Computational Thinking Learning Trajectory. *In Proceedings of the 2018 ACM Conference on International Computing Education Research* (pp. 124-132). Espoo, Finland: ACM.

Rich, K. M., Strickland, C., Binkowski, T. A. and Franklin, D. (2019). A K-8 Debugging Learning Trajectory Derived from Research Literature. In *Proceedings of the 50th ACM Technical Symposium on Computer Science Education* (pp. 745-751), Minneapolis, USA: ACM.

Seiter, L., Foreman, B. (2013). Modelling the Learning Progressions of Computational Thinking of Primary Grade Students. In *Proceedings of the 9th Annual International ACM Conference on International Computing Education Research* (pp. 59-66), San Diego, San California, USA: ACM

Sorva, J. (2013). Notional Machines and Introductory Programming Education. ACM Transactions on Computing Education, 13(2), Article 8. Retrieved from https://dl.acm.org/citation.cfm?id=2483713

Teague, D. (2015). Neo-Piagetian Theory and the Novice Programmer. PhD by Publication, Queensland University of Technology. Retrieved from https://eprints.qut.edu.au/86690/

Rosa, A. & Montero, I. (1990). The Historical Context of Vygotsky's Work: A Sociohistorical Approach. In Moll, L.C. (Ed.) *Vygotsky and Education: Instructional Implications and Applications of Sociohistorical Psychology.* New York, NY: Cambridge University Press.

Welsh Government. (2015). A Curriculum for Wales - A Curriculum for Life. Cardiff: Welsh Government. Retrieved from https://dera.ioe.ac.uk/24680/1/151021-a-curriculum-for-wales-a-curriculum-for-life-en_Redacted.pdf

Wheater, R., Ager, R., Burge, B. and Sizmur, J. (2013). Achievement of 15-Year-Olds in Wales: PISA 2012 National Report (OECD Programme for International Student Assessment). Slough: NFER. Retrieved from http://www.nfer.ac.uk/publications/PQUK02

Wong, G.K. and Jiang, S. (2018). Computational Thinking Education for Children: Algorithmic Thinking and Debugging. In *2018 IEEE International Conference on Teaching, Assessment, and Learning for Engineering (TALE)* (pp. 328-334). Wollongong, NSW, Australia: IEEE.

Wyeth, P. (2008). How Young Children Learn to Program with Sensor, Action, and Logic Blocks. Journal of the Learning Sciences, 17(4), (pp.517–550). Retrieved from https://doi.org/10.1080/10508400802395069

Wyse, D., Hayward, L. and Pandya, J. (2016). Introduction. In Wyse, D., Hayward, L. and Pandya, J. (Eds.). *The Sage Handbook of Curriculum, Pedagogy and Assessment.* Sage Publications (pp. 1-26). London.