Institution: University of Winchester

Unit of Assessment: 23

Title of case study:

The Centre for Real-World Learning: Reframing education for engineering through research on habits of mind and signature pedagogies

Period when the underpinning research was undertaken: 2013-2020

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Professor Bill Lucas	Director of the Centre for Real World Learning	2008 - present
Dr Janet Hanson	Researcher	2013 - present

Period when the claimed impact occurred: 2014 - 2020

Is this case study continued from a case study submitted in 2014? No

1. Summary of the impact

Centre for Real-World Learning (CRL) research is transforming the way education for engineering in schools is conceived in England/internationally, inspiring changes in teaching practices. Traditionally seen through the lens of subjects like physics and mathematics, engineering has been reframed through CRL's research as a set of engineering habits of mind, which has become a core model for the Royal Academy of Engineering and schools across the world. Selected by the Institution of Mechanical Engineers in 2016 as one of six big ideas for the global future of engineering education, CRL's model is used in UK, Norway, Australia, Sweden and Germany.

2. Underpinning research

Across the world we do not have enough engineers. Moreover, the engineering profession lacks diversity and is overwhelmingly male. In schools, especially secondary, where timetables are organised by subject disciplines, engineering is almost invisible. Most schoolteachers lack direct experience of engineering and expect pupils to study the traditional subjects of physics and mathematics for entry to engineering, a path that is proving less likely to result in the creative, collaborative and problem-solving mind-sets that modern engineering desperately needs [5.1, 5.2].

This appears to be a supply and demand problem. The world needs engineers and schools cannot generate enough students who want to go on and study it. But what if this were a problem of conceptualisation? What if we do not understand how engineers think/act and therefore don't know how best to teach would-be engineers at school?

This was the hypothesis with which CRL approached research commissioned by the Royal Academy of Engineering (RAEng) in 2013. The research has followed a three-phase trajectory:

1. Synthesising evidence and expert opinion to produce a theoretical concept - engineering habits of mind (EHoM) and their associated teaching methods [3.1, 3.2]
2. Conducting an intervention study in England/Scotland as a proof of concept trial of EHoM, using teacher professional development to enable tests of change in classrooms [3.3]
3. Undertaking a global review of effective school leadership practices associated with issues which, like engineering, are important but not mandated in schools and correlating this, using a positive deviance approach, with a group of school leaders in England to understand more about what leadership style is conducive to the promotion of engineering [3.4]. Then looking at initial teacher training [3.5] and finally widening the

scope to study practical learning in general in response to declining numbers of pupils studying creative and technical subjects [5.1].

Phase 1 - Developing a concept – engineering habits of mind with their signature pedagogies
A framework composed of six EHoM surrounding the core engineering mind of Making 'things' that work and making 'things' work better' was developed and validated through in-depth interviews with engineers and an online survey distributed by RAEng, Figure 1.

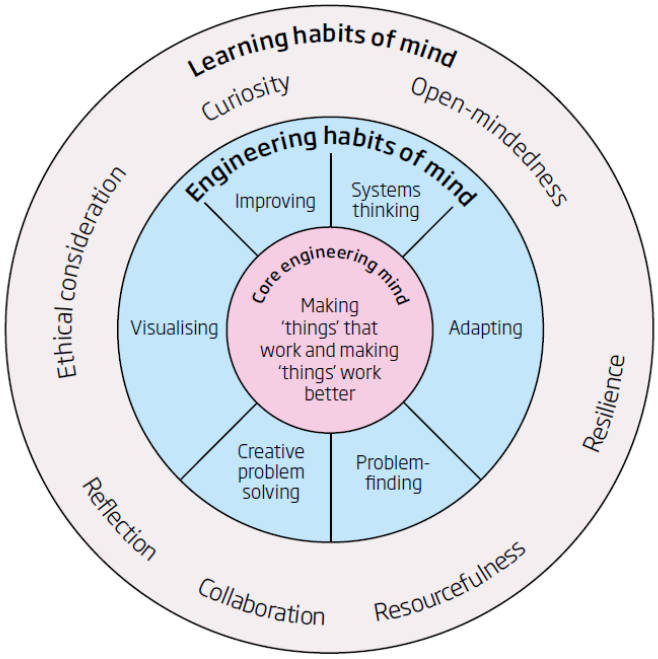

Figure 1 – CRL's Engineering Habits of Mind

At the same time CRL's research identified some key 'signature pedagogies', teaching methods which the literature suggested were most likely to cultivate the desired habits of mind [3.1, 3.2].

Phase 2 - Establishing a proof of concept that EHoM and their signature pedagogies work
Over the period 2014-2016, in partnership with University of Manchester and Primary Engineer, CRL established that teachers find the EHoM framing helpful, can apply the concept of signature pedagogies in practice and, with targeted professional development, can change their practices to incorporate engineering in their teaching [3.3].

Phase 3 – From small scale to the possibility of system change
In 2017-2018 CRL developed a model of school leadership which explores the influence of external context, the culture of school, the personal attributes of the leader and leadership strategies which are most effective in promoting engineering in schools [3.4].

As a result of the impact of CRL's work in primary education, in 2018 RAEng commissioned CRL to undertake a small-scale intervention study to understand how initial teacher training can better prepare primary teachers to encourage children to think like an engineer [3.5]. In 2019 the RAEng commissioned CRL to rethink the role of practical learning in schools more generally. To date CRL has received £151,425 for this research.

Each study had an expert advisory board and reports were peer reviewed. Members/reviewers included Professor John Perkins, former Scientific Adviser to UK Government/author of *Perkins' Review of Engineering Skills*, Professor Peter Goodhew, Professor Emeritus, NMITE, Dr David Knott, Chief of R&T Design Systems Engineering, Rolls Royce, Dr Susan Scurlock, CEO, Primary Engineer, Georgina Mulhall, Executive Headteacher, Gomer Junior School.

3. References to the research (indicative maximum of six references)

3.1 Lucas, B., Hanson, J. and Claxton, G. (2014). *Thinking like an engineer: Implications for the education system.* London: Royal Academy of Engineering.
https://www.raeng.org.uk/publications/reports/thinking-like-an-engineer-implications-full-report
3.2 Lucas, B. and Hanson, J. (2016). Thinking Like an Engineer: Using Engineering Habits of Mind and signature pedagogies to redesign Engineering Education. *International Journal of Engineering Pedagogy*, 6 (2) 4-13. [submitted in REF2a]
https://online-journals.org/index.php/i-jep/article/view/5366/3948
3.3 Lucas, B., Hanson, J., Bianchi, L. and Chippindall, J. (2017). *Learning to be an engineer: Implications for the education system. London*: Royal Academy of Engineering.
https://www.raeng.org.uk/publications/reports/learning-to-be-an-engineer
3.4 Lucas, B. and Hanson, J. (2018). *Learning to be an engineer: the role of school leadership*. London: Royal Academy of Engineering.
https://www.raeng.org.uk/publications/reports/learning-to-be-an-engineer-the-role-of-school-lead
3.5 Hanson, J., Hardman, S., Luke, S., Maunders, P. and Lucas, B. (2018). *Engineering the future: training today's teachers to develop tomorrow's engineers.* London: Royal Academy of Engineering.
https://www.raeng.org.uk/publications/reports/engineering-the-future-training-today-s-teachers-t

Underpinning research outputs 3.2 and 3.3 were peer-reviewed by external assessors and scored at 2* and above.

4. Details of the impact

Since its publication in 2014 [3.1] CRL's research into the EHoM model, associated teaching methods [3.2, 3.3] and leadership implications [3.4] have directly impacted on national education policy thinking by helping to shift engineering education narratives from focusing on bridging a specific skills deficit to a more inclusive framing of engineering as a cross-disciplinary way of thinking/behaving that improves people's lives.

Impact on national policy

A senior representative of Royal Academy of Engineering stated that EHoM has 'had a major impact' [5.6] on the influential RAEng as a way of reframing engineering to address the shortage of engineers and lack of diversity in young people choosing it as a career [5.6]. While Professor John Perkins' *Review of Engineering Skills* (2013) made no mention of 'engineering thinking', by 2019 the update, *Engineering skills for the future: The 2013 Perkins Review revisited* [5.1], specifically references CRL's work: 'The Royal Academy of Engineering in partnership with the University of Winchester described the need to develop in learners a series of engineering habits of mind…They have been working with schools and other organisations to embed them in the education system' (p.24). CRL has 'also directly impacted on the RAEng's own strategy development' [5.6]. The impact of CRL's reframing is similarly noted by the Royal Society [5.7].

The impact of EHoM was further recognised by the Institution of Mechanical Engineers (IMechE) when in 2018 it selected EHoM as one of the 'big ideas' of the decade in engineering education [5.2, 5.7]. The report acknowledges CRL's contribution to ways of enhancing the image of engineering and the supply of engineers through EHoM and identified from its wide-ranging survey of 2,500 stakeholders that '…there was very strong support across all groups for schools to encourage developing engineering habits of mind' (p.20) and that 'Developing engineering habits of mind and nurturing problem-solving skills would result in a much larger pool of young people able to pursue engineering or related technical professions' (p.39). As an indicator of CRL's influence Lucas was invited, in 2018, to deliver a keynote at RAEng's conference *Engineering education systems that are fit for the future* and in 2019 IMECHE invited Lucas/Hanson to participate in a policy consultation 'Can anyone be an Engineer?' in partnership with St George's House, Windsor [5.7]. In 2018 the RAEng led a project to propose a common core for T levels, new vocational courses, in *Engineering and manufacturing.* RAEng recommended that 'T levels should…seek to develop an *engineering mind-set* among learners.

The attributes and characteristics of engineers and technicians identified by the Royal Academy of Engineering include problem finding, creative problem solving, adapting, visualising, improving and systems thinking…and should be built into the teaching and learning of T levels for E&M' (p5) [5.3], explicitly referencing CRL's work.

Impact on national teaching practices

CRL's 2017 proof-of-concept research [3.3], a collaboration with University of Manchester [5.8] and Primary Engineer [5.9], involved a network of 32 schools in Southern England, Greater Manchester and Scotland. 34 teachers taught lessons to c.3,000 pupils using EHoM. Teachers reported that pupils not only demonstrated EHoM but also that their literacy and oracy skills were enhanced. The findings were considered significant enough to be covered by the BBC [5.4]. Two of the Southern England schools involved in the 2017 research, Gomer Junior School [5.10] and Bohunt School [5.11], have since become members of multi-academy trusts and have expanded their use of EHoM to their new partners. EHoM are now 'integral to the effectiveness' of 'learners and teachers across a range of subject domains' [5.10]. The resources created through CRL's research have been developed by RAEng to promote the 'human face' of engineering and attract a more diverse audience. Initially resources were created to celebrate the centenary of the Royal Air Force - *RAF100: Aiming for Awesome.* Material now includes an interactive EHoM quiz for children to identify their EHoM, https://www.raeng.org.uk/education/schools/teaching-and-learning-resources/raf100. To mark *This is Engineering Day* (04 November 2020), around 17,500 individual student packs were distributed via c.1,000 schools across the UK. The national teacher development hub, STEM Learning, makes extensive use of EHoM in its workshops.

The University of Manchester [5.8] has built on EHoM research by exploring the signature pedagogy of 'tinkering', collaborating to publish 'A scoping literature review of learning progressions of engineering education at primary and secondary school level' in *Research in Science and Technological Education,* as a way of tracking the development of EHoM. EHoM is used in 167 schools by 233 teachers with more than 5,000 pupils in the Manchester area [5.8].

In Scotland, Primary Engineer uses EHoM as a model to underpin CPD with teachers and in a PG Certificate in Engineering STEM Learning with University of Strathclyde [5.9]. The programme is recognised by the General Teaching Council for Scotland. To date 33 teachers in 28 schools have been involved in the programme [5.9]. One of the most significant impacts of CRL's research has been the re-focusing of attention on engineering in the early years/primary levels instead of beginning at secondary level. A teacher from Pitteuchar East Primary School and a graduate of the Primary Engineer PGCert., gave evidence to the Scottish Parliament's inquiry into STEM in Early Years Education about the benefits of using EHoM [5.5]. As of January 2021, 50 teachers have undertaken professional enquiries using EHoM [5.9].

In 2020 Lucas was the first speaker in the RAEng's Lockdown policy webinar series reflecting on how CRL's work in engineering and creativity had changed policy/practice to incorporate creative and engineering habits of mind, https://www.youtube.com/watch?v=1Ty3MIDPZ3s. In 2020 EngineeringUK asked Hanson to contribute to a consultation on developing an impact framework for STEM outreach activities; Lucas was invited to contribute to the APPG on Diversity and Inclusion in STEM education, https://www.britishscienceassociation.org/appg.

Impact on museum learning

Soon after the EHoM model was published [3.1], London's Science Museum, in collaboration with RAEng, adopted it to underpin a major interactive exhibition *Engineer your future,* designed to help young teens find out more about the 'engineering brain' to interest them in a career in engineering. The exhibition, opened by HRH The Prince of Wales in 2015, is still running and by 2018 had attracted 45,003 student visitors and 5,389 teachers/accompanying adults, https://www.sciencemuseum.org.uk/see-and-do/engineer-your-future. A similar themed exhibition showcasing CRL's six EHoM called *Future Engineers* was launched by the London Transport Museum in 2018. It has attracted over 20,000 pupils and 1,600 teachers, https://www.ltmuseum.co.uk/visit/museum-guide/future-engineers. The RAEng notes CRL's impact on museum learning [5.6].

Impact on higher education teaching practice
Although CRL's research has been within the compulsory education sector, EHoM has made a considerable impact on higher education engineering departments seeking to change perceptions about engineering. 'EHoM in combination with CDIO is supporting our ambitious vision for engineering' [5.12]. Many of the 30 or so UK and international institutions that are building on CRL's work are making greater use of student-centred pedagogies such as project-based learning to encourage cross-disciplinary learning and to develop EHoM within students' employability skill-sets as at Canterbury Christ Church University [5.12]. Other HE examples include Twente (Netherlands), Ruhr-Universität Bochum (Germany), Southern Cross (Australia), Chalmers (Sweden), and San Diego (USA). Indicative of these is a first year electrical engineering course in Norway adopting EHoM, 'it is important to explore pedagogical approaches that can support students in their development of engineering habits of mind' (p.2) *European Journal of Engineering Education* (DOI:10.1080/03043797.2020.1789069).

Impact on thinking among international educationalists
In Australia, the EHoM model has influenced all levels of education thinking from primary to higher education, where the Australian Council of Engineering Deans endorsed EHoM findings *'What will not change is the fundamental purpose of a formal engineering education being about learning how to learn, nurturing the deployment of engineering habits of mind'* p.49 http://www.aced.edu.au/downloads/Engineering%20Futures%202035_Stage%201%20report%20for%20ACED_May_16_2019.pdf. UNESCO/UNEVOC writes: 'Thinking like an engineer makes a strong case to suggest that, if the UK wants to produce more engineers, it needs to redesign the education system so that the six engineering habits of mind identified in the book become the desired outcomes of engineering education.' https://unevoc.unesco.org/bilt/BILT+publications/lang=enaktaktakt/akt=detail/qs=5777. Lucas/Hanson have been invited to participate in a bid founded on EHoM to the National Science Foundation "Increasing the Capacity of 9-12 Teachers of Engineering" with Teachers College, Columbia University, New York.

5. Sources to corroborate the impact (indicative maximum of 10 references)

Documents/Websites
5.1 Royal Academy of Engineering (2019*) Engineering skills for the future: The 2013 Perkins Review revisited*. London: Royal Academy of Engineering.
https://www.raeng.org.uk/publications/reports/engineering-skills-for-the-future
5.2 Institution of Mechanical Engineers (2018) *Big Ideas: The future of engineering in schools*. London: Institution of Mechanical Engineers.
https://www.stem.org.uk/resources/elibrary/resource/105969/big-ideas-future-engineering-schools#&gid=undefined&pid=1
5.3 Royal Academy of Engineering (2018) *Engineering & Manufacturing T level: Common core content.* London: Royal Academy of Engineering.
https://www.raeng.org.uk/publications/other/t-level,-engineering-and-manufacturing-core-conten
5.4 Burns, J. (2017, March 31). Teach 'problem solving' to produce engineers, schools urged. BBC News. https://www.bbc.co.uk/news/education-39422630
5.5 Scottish Parliament, Education and Skills Committee (2019) Report on STEM in early years education. SP Paper 624 8th Report, 2019 (Session 5)
https://www.parliament.scot/parliamentarybusiness/CurrentCommittees/111655.aspx

Individuals/organisations
5.6 Senior representative of Royal Academy of Engineering
5.7 Senior representative of Education and Skills at Royal Society
5.8 Representative of The University of Manchester
5.9 Senior representative of Primary Engineer
5.10 Senior representative of Gosport & Fareham Multi-Academy Trust
5.11 Senior representative of Bohunt Education Trust
5.12 Senior representative of Canterbury Christ Church University