Impact case study (REF3b)

Institution: **University of Glasgow**
Unit of Assessment: **B11 – Computer Science and Informatics**
Title of case study: **Transforming computing science education to confront global industry skills gap**
1. Summary of the impact

With computing science in schools and universities suffering from an international education crisis, University of Glasgow research has driven the development of new school curriculum across the UK. The learning and teaching materials developed at Glasgow rethink the way computing science is taught, with over 10,000 pupils taking part in workshops in Scotland and 1,600 teachers in 20 countries using the materials. In the US, this research has attracted 20 high schools and 2,000 university students into programmes demonstrating new methods in teaching computational thinking. Dr Quintin Cutts has also contributed to the Scottish Qualifications Authority's assessments for the new Scottish curriculum, consulting on assessment techniques and nationwide Computing Science exam papers.

2. Underpinning research

Computing science is often taught as a dated basic introduction to office software packages or a 'digital literacy' course, rather than an app-creating, games-building, technology-developing, informatics-designing discipline. Computing science education at school level is also not recognised as a requirement for higher education, with universities preferring maths or science subjects. Furthermore, even university-level computing science education is not producing enough graduates with skills in computational thinking and problem-solving, leading to an industry-wide skills gap.

Dr Quintin Cutts (Senior Lecturer, Computing Science, 1995-present) has researched computing science education generally, computer programming education in particular, and the use of technology to enhance face-to-face education, over a period of 15 years. From 1997-2000, Cutts was a researcher in a joint learning and teaching project with the School of Education at the University of Glasgow. His research was focused on the extent to which the ability to program is innate or can be learned. Finding the standard lecture format used to teach programming was inadequate in helping students to develop the skills required [1] led to his interest in developing better methods of teaching programming skills, most notably how to teach abstract and computational thinking.

From 2000-2004, Cutts researched the application (to education) of electronic voting systems in developing computational thinking. These systems enable students to vote quickly on a topic, and to record their answers. The primary purpose was to get students to think about the reasons for choosing certain answers, to consider alternate responses to the same question and thereby develop a significantly deeper understanding of the topics. He found a positive association between students' use of electronic voting systems and their learning outcomes: those students using the systems provided more accurate responses relative to the rest of their class [2]. Furthermore, the use of electronic voting systems stimulated increased discussion amongst students and between students and teachers, helping them to develop computational thinking skills.

From September 2005 to September 2009, Cutts was the Principal Investigator on the EPSRC-funded 'Computing Science Inside' research project (£155k). Developed as a response to very low enrolment levels for computing science in secondary school and university courses, this Partnerships in Public Engagement project built on Cutts' educational skills and research to develop materials for schools [3]. Cutts found that teachers were very poorly supported with regard to high-quality teaching and learning materials, and particularly those embodying the latest research findings on computing science pedagogy. The examination system was recognised as a

major contributory factor underpinning these issues, encouraging a rote-learning approach entirely unsuitable to the subject.

In 2008, Cutts returned his focus to the teaching of programming. From 2008-2010 he applied Carol Dweck's Mindset research programme (which considers methods to encourage learning through effort rather than relying on presumed innate ability) to computing science education, publishing the first study to demonstrate improvements in the performance of computing science students as a result of exposure to Mindset concepts [4]. This provided further evidence against programming being an innate skill and therefore meriting further investigation to identify and develop more effective learning and teaching methods.

From 2010-2012, Cutts and Dr Beth Simon (University of California, San Diego) applied their prior experiences in both Mindset and electronic voting systems to a collaborative research project on the learning of programming. They were the first to report educational benefits from applying the Peer Instruction methodology to introductory programming classes. They co-developed and evaluated a course to foster computational thinking skills; Cutts was instrumental in shaping the instructional design. This work has led to a string of ground-breaking publications on the design of computational thinking courses [5] and on appropriate learning, teaching and assessment practices in programming education [6].

3. References to the research

1. Cutts, Q.I., 'Engaging a Large First Year Class', in *Reconstructing Professionalism in University Teaching*, M. Walker (Ed.), Buckingham: Open University Press, pp 105-128 (2001). ISBN 0335208169 (pb) 0335208177 (hb) [available from HEI]
2. Kennedy, GE, and Cutts, QI (2005) The association between students' use of an electronic voting system and their learning outcomes. *Journal of Computer Assisted Learning*, 21. pp. 260-268. (doi:10.1111/j.1365-2729.2005.00133.x)*
3. Curzon, P., McOwan, P., Cutts, Q., and Bell, T. (2009) Enthusing and inspiring with reusable kinaesthetic activities. In: ITiCSE '09 Proceedings of the 14th Annual ACM SIGCSE Conference on Innovation and Technology in Computer Science Education, 3-7 Jul 2009, Paris, France. [Link, or available from HEI]
4. Cutts, Q., Cutts, E., Draper, S., O'Donnell, P., and Saffrey, P. (2010) Manipulating mindset to positively influence introductory programming performance. In: SIGCSE '10 Proceedings of the 41st ACM Technical Symposium on Computer Science education, 10-13 Mar 2010, Milwaukee, USA. [Link, or available from HEI]*
5. Cutts, Q., Esper, S. and Simon, B. (2011) 'Computing as the 4th R: A General Education Approach to Computing Education', Proceedings of ICER'11, 7th International Computing Education Research Workshop, August 2011, Providence, Rhode Island, USA. pp 133-138. [doi 10.1145/2016911.2016938, or available from HEI]*
6. Cutts, Q., Esper, S., Fecho, M., Foster, S. & Simon, B. (2012) 'The Abstraction Transition Taxonomy: Developing Desired Learning Outcomes through the Lens of Situated Cognition' Proceedings of ICER 12, the 9th International Computing Education Research Conference, Auckland, New Zealand, Sept. 2012. ISBN 9781450316040 [Link, or available from HEI]

* best indicators of quality

4. Details of the impact

Failing to recruit enough students or properly tailoring graduates for jobs has caused increased unemployment and a widening skills gap in the computing science industry. In particular, employers report a lack of programming skills. The University of Glasgow research led by Quintin Cutts has developed methods of teaching students at school and university levels which address this gap, and aim to improve the number of students taking computing science at university.

Computing Science Education in the United States
Cutts' work in the US has influenced the development of three National Science Foundation projects aiming to improve computing science education: CS10k (training 10,000 new teachers by 2020); CE21 (developing computing education to meet 21st century needs); and CS Principles (developing courses in Computational Thinking at secondary school level). All three programmes were launched in 2009-10. In 2010-11, Cutts co-designed and evaluated a CS Principles pilot course delivered to over 1,000 non-specialist university students at the University of California, San Diego (UCSD). The course is currently (2013) being trialled in 20-30 secondary schools in the San Diego area and has received extensive publicity in the US, including distribution through Association of Computing Machinery publications. The course is contributing to the development of an Advanced Placement course: a college-entry level qualification undertaken by secondary school students (20% in 2012). In the US, each state runs its own curriculum and qualification requirements; the Advanced Placement courses are unique in being standardised across the country. Cleveland State, in collaboration with UCSD has also been funded by the CE-21 programme to use the course in the development of professional training for 30-40 teachers across the state.

Computing Science Inside: UK Student Activities and Teacher Workshops
In the UK, the EPSRC-funded 'Computing Science Inside' project aimed to demonstrate the true nature of computing science to pupils as a subject to be studied at school and university. The project also hoped to have a strong influence on teachers and their approach to current teaching practices. The project (available at http://csi.dcs.gla.ac.uk) delivered continuing professional development (CPD) to UK teachers and developed 15 workshop resources for teachers worldwide. 'Computing Science Inside' ran from September 2005-September 2009, but teachers are still able to register, access and utilise the site.
- During the 4-year project, over 5,500 pupils in Scotland participated in at least one workshop, with many attending 6 or more (~2,400 from the start of the impact period Jan 2008).
- At the formal conclusion of the project in 2009 there were 92 schools from the rest of the UK (rUK) involved. As of July 2013, another 100 rUK schools have registered and utilised the site. (These numbers do not account for the sharing of resources between schools independently of the website.) Outside the UK, ~1600 teachers from over 250 schools in 20 countries are currently registered on the website.
- The project provided over 1,300 person hours of CPD to teachers and trainee teachers. One said "I simply didn't know you could teach computing science this way", referring to the active and engaged kinaesthetic teaching and learning methods used. Written feedback from over 50 teachers was all positive, with comments including: "Hands-on interactive approach made understanding the concepts easy for the pupils"; "One or two of the weaker pupils made unexpected contributions showing insights that they had not managed before"; and "One very bright girl is now considering doing Computing at university".
- The programme lives on in a University of Glasgow initiative which is being replicated elsewhere in Scotland. University students spend 10 half-days in local schools, presenting existing and creating new workshops in the 'Computing Science Inside' style. Over the past six years (2007-13) the initiative has directly reached a further 5,800 pupils and 150 teachers. In 2008 the course was replicated at Heriot-Watt and Glasgow Caledonian Universities; efforts are underway to do the same at the Universities of Dundee and Edinburgh.

Scottish Curriculum for Excellence
In 2010, Cutts drove the effort to ensure that Computing Science appeared as a specific curriculum area within Scotland's new national Curriculum for Excellence. The key issue, as identified in the Royal Society 'Shut Down or Restart' report on the state of computing education in the UK, is to separate the teaching of how to use computers (*Information and Communications Technology*) from the teaching of how to understand computation and create programs (*Computing Science*). In 2010 the Higher Education Academy recognised Cutts' efforts with a 2010 National Award for Teaching of Information and Computing Science in Higher Education.

In further recognition of his success in building a rapport between higher education institutions and schools, in 2011 Cutts became one of two academic members of the Qualification Design Team for

the Scottish Qualifications Authority (SQA) with a remit of overseeing new qualifications in Computing Science. The National 5 qualification is scheduled for implementation in the school year 2013/14, Higher in 2014/15, and Advanced Higher in 2015/16. Cutts also became a board member of the Royal Society of Edinburgh Computing exemplification project, supporting the development of materials for the new Scottish curriculum and qualifications. The materials have been widely acclaimed by Scottish teachers, Education Scotland, the SQA, as well as luminaries in the computing science education community, including Hal Abelson at MIT. Cutts' impact was to emphasise that *understanding* of programs and programming concepts is at least as important as being able to *develop* programs. Furthermore, he has instilled research-proven methods of formative and summative assessment of programming skills that go beyond the typical 'submit a program and mark it', giving greater insight into the learner's progress.

Cutts has been instrumental in negotiating with the SQA to raise the rigour of their examinations. Cutts developed the pseudo-code 'Haggis', with Professor Michaelson of Heriot-Watt University, to alleviate the problem of setting exam questions for students who will have studied any one of a number of programming languages. 'Haggis' was adopted by the SQA in January 2013 for use in nationwide computing science exam papers in summer 2014. Most recently, as a member of the Scottish Government's Computing in the Curriculum Group, he authored a proposal for CPD in Computing Science (computational thinking and computing science pedagogy) for the ~700 computing teachers in Scotland. This has now been funded by the Scottish Government for two years (£400,000), and Cutts is seconded three days per week to lead the project.

5. Sources to corroborate the impact

- Computing Science Inside: http://csi.dcs.gla.ac.uk
- Computing Science Principles (US) course progress and information
- Press Release, UK Department for Education, 24 April 2013

Testimonials:
- Chair, Computing at School Scotland (on Cutts' standing in the Scottish teaching community)
- Principal Researcher, Microsoft Research (on wider standing within the community)
- Qualifications Manager, Scottish Qualifications Authority (on contribution to SQA, assessment designs and Haggis pseudocode)
- Convener of the Education Committee, Royal Society of Edinburgh (on contribution to Royal Society of Edinburgh's exemplification project)
- Associate Director of Learning Sciences and Technology and Lecturer in Computer Science and Engineering, University of California, San Diego (on contribution to the Computing Science Principles pilot programme)