Institution: Birkbeck, University of London

Unit of Assessment: UoA 11 Computer Science and Informatics

Title of case study: Intelligent Constructionist Tools for Learning and Teaching

1. Summary of the impact

This case study describes impact arising from research into designing constructionist tools that provide personalisation, support and guidance to learners and teachers, resulting in software used in several schools, FE colleges and universities world-wide. Constructionist learning is founded on the principle of *constructionism* which argues for the pedagogical importance of building artefacts as a way of building mental representations. A key computational challenge in the design of tools that foster constructionist learning is to provide intelligent support that guides users towards productive interaction with the tool without constraining its creative potential.

2. Underpinning research

In education, knowledge may be assimilated through a process of *construction,* whereby individuals and peers explore a particular concept, reflect on it, and rebuild it by reformulating its representation (Harel and Papert, *Constructionism*, 1991). Our research is founded on a pedagogical view that combines constructionism with Laurillard's Conversational Framework (Laurillard, *Rethinking university teaching: a conversational framework for the effective use of learning technologies*, 2002), considering learning as an iterative process of building mental representations through construction, reflection, sharing and collaboration between the digital environment, the teacher, the learner and their peers.

Our research began in the mid 2000s and has progressed along two major directions: *intelligence-based tools to aid students and teachers in assimilating knowledge of a domain through iterative construction of an artefact*; and *intelligence-based learning analytics to assist teachers*. We follow an interdisciplinary research methodology in which pedagogical theory informs the initial design of algorithms and tools; these are then iteratively evolved and enhanced through successive cycles of user-centred evaluation; concurrently, pedagogical theory and practice are transformed through the provision of our tools to education experts and practitioners. Much of the research has been undertaken as part of the LDSE project (2008-11) and the MiGen project (2007-11), both funded as part of the ESRC/EPSRC Technology Enhanced Learning (TEL) Programme and undertaken in collaboration with staff from the Institute of Education (IoE) and other education specialists and practitioners.

Our approach to designing intelligent support for the learner goes beyond standard approaches to user modelling in that we model users' learning as manifested by the artefacts they are constructing. The systems that we build are not Intelligent Tutoring Systems (ITS) in the traditional sense: in constructionist environments, there is not a well-defined mapping between sequences of users' actions and explicit acquisition of knowledge; instead, there is an iterative process of negotiation and co-construction of knowledge, rendering the design of intelligent support for users much more challenging. Several of our techniques for generating feedback for the user are based on similarity matching, e.g. those used in LDSE to compare a learning design that the user is constructing against similar existing ones [1,2], and those used in MiGen to compare students' construction activities against known patterns of productive and unproductive interaction [3] and to group students for collaborative learning activities [4].

The LDSE project was motivated by the need to support lecturers and teachers in capturing their pedagogic ideas, testing them out and reworking them, allowing them to build on what others have done before and to share their results with their community. We developed the ***Learning Designer*** system [1,2] that helps users to assimilate knowledge of the domain of learning design through construction, reflection, collaboration and sharing of learning design artefacts. These take the form of "pedagogic patterns" – a temporal sequence of teaching and learning activities addressing a specified learning outcome – which users can adapt to their own context. At the heart of the Learning Designer is an ontology that models core concepts of learning theory and practice with respect to which each learning design is annotated (by the user and by the system). The system searches for existing learning designs similar to the one being worked on by the user in order to generate personalised feedback according to the user's context and the stated learning goals of their design. The system generates analytics based on the learning design properties and

annotations in order to support teachers in viewing their designs from different perspectives, for example the individual, group-based and class-based dimensions of the learning activities. The Learning Designer was the first tool to support this kind of visual feedback and pedagogic analysis of lesson plans.

The MiGen project focussed on the learning and teaching of algebra, which is notoriously difficult for children to learn. We designed a constructionist environment for use in the classroom, called ***eXpresser,*** that transforms the learning of algebraic concepts. Instead of working with symbols and equations, students use eXpresser to construct 2-D tiling patterns and, at the same time, algebraic rules about properties of their patterns. MiGen's main intelligent component, the ***eGeneraliser***, gathers information about students' construction activities and uses this to make inferences about students' progress in knowledge assimilation. This inferred information is used to generate personalised feedback for students during their construction in order to foster productive interaction with eXpresser. A key computational challenge is to provide real-time feedback to students *without* destroying the exploratory and creative potential of their interaction, and this is a major contribution of the research [3].

The information inferred by the eGeneraliser is used by a suite of ***Teacher Assistance (TA) tools*** that allow the teacher to monitor students' progress as they are working with eXpresser [5]. These tools enable the teacher to provide individual support to students, even when working with a class of 30 children. These tools represent the first work targeted at visualising students' progress through constructionist learning tasks and at notifying teachers of students' attainment of knowledge-building landmarks. There is, of course, much previous work in developing tools that assist teachers in an *instructionist* role. However, ours was the first work aiming to assist teachers in tracking their students' progress during *constructionist* learning activities.

Staff involved in the research and Birkbeck contribution

Birkbeck academic staff Professors G.Magoulas and A.Poulovassilis were Principal Investigators (PIs) on the LDSE and MiGen projects, respectively. Birkbeck Postdoctoral staff were Dr S.Gutierrez-Santos (Oct. 2007 – Dec. 2011), now a Lecturer at Birkbeck; Dr D.Pearce-Lazard (Oct. 2007 – Aug. 2010); Dr P.Charlton (Nov. 2008 – Nov. 2011); and D.Dimakopoulos (May 2010 – Nov. 2011). M.Cocea was a PhD student (Oct.2007 – Aug. 2010) associated with the MiGen project. The lead PI on the LDSE project was Professor Diana Laurillard, IoE. The lead PI on the MiGen project was Professor Richard Noss, IoE.

The Birkbeck contribution has been in the research, design and implementation of the eGeneraliser, the TA tools, and the overall client-server architecture of the MiGen system; the research, design and implementation of the first prototype of MiGen's eXpresser; the research, design and implementation of the intelligent components of the Learning Designer; and the design and implementation of the whole Learning Designer system.

3. References to the research

Publications (Birkbeck authors shown in bold)

[1] **Charlton P., Magoulas G.D.,** Laurillard D. (2012). Enabling Creative Learning Design through Semantic Technologies. *Technology, Pedagogy and Education Journal*, 21(2), pp 231-253. DOI 10.1080/1475939X.2012.698165

[2] **Charlton P., Magoulas G.D.** (2010). Autonomic Computing and Ontologies to Enable Context-aware Learning Design, *Proceedings 22nd IEEE International Conference on Tools with Artificial Intelligence*, Arras, France, pp. 286-291. DOI 10.1109/ICTAI.2010.113

[3] R.Noss, **A.Poulovassilis**, E.Geraniou, **S.Gutierrez-Santos**, C.Hoyles, K.Kahn, **G.D. Magoulas**, M.Mavrikis (2012). The design of a system to support exploratory learning of algebraic generalisation, *Computers and Education*, 59(1), pp 63-81. DOI 10.1016/j.compedu.2011.09.021

[4] **M.Cocea, G. D. Magoulas** (2012): User behaviour-driven group formation through case-based reasoning and clustering. Expert Systems with Applications, 39(10), pp 8756–8768. DOI 10.1016/j.eswa.2012.01.205

[5] **S.Gutierrez-Santos,** E.Geraniou, **D.Pearce-Lazard, A.Poulovassilis** (2012). Design of Teacher Assistance Tools in an Exploratory Learning Environment for Algebraic Generalisation,

IEEE Transactions in Learning Technologies, 5(4) pp 366-376. DOI 10.1109/IS.2010.5548380

Research Grants

The LDSE project ("Learning Design Support Environment", Nov. 2008-Nov. 2011) and the MiGen project ("Intelligent Support for Mathematical Generalisation", Oct. 2007-June 2011) were two of the 8 projects funded by the ESRC/EPSRC TEL Programme over its two Calls (see http://www.tel.ac.uk/ for information about the programme and its 8 projects). The total value of the LDSE grant was about £1.5M of which about £300,000 was awarded to Birkbeck and the rest to IoE, Oxford, London School of Economics, Royal Veterinary College and London Metropolitan University. The total value of the MiGen grant was about £1.3M, of which about £600,000 was awarded to Birkbeck and the rest to IoE.

4. Details of the impact

(1) The independent Insight Report (R. A Harris, *Contexts of use of Learning Design Support Tools*, December 2011, available at https://sites.google.com/a/lkl.ac.uk/ldse/) asked the Association for Learning Technologies community of education practitioners what key contributions the LDSE project had made, as part of an on-line survey. Respondents suggested it had increased awareness of learning design support tools and pedagogy, enabled the move from research to practice in the use of learning design tools, and advanced the visualisation of learning designs. The following are excerpts from some of the responses:

"Drawing together some of the best research of the [past] decade into a usable tool."

"The key point is it attempts to link to pedagogy and facilitate this process for users. What's important is that users can engage with the tool without having a good working knowledge of their pedagogy. In this context, the tool could be used to raise awareness of pedagogical theory."

"Move away from a template-based, gap-filling approach. The perception is that such approaches trivialise the serious matter of pedagogical design."

"We now have a demonstrable framework to use when discussing these issues in other institutions."

"It has allowed for another (considerable) advance in the visualisation of designs."

"The tool is user-friendly and not intimidating. [...] I do think it encourages new staff to think about good learning design, and encourages them to collaborate and learn from others, and in this respect, the LDSE tool could be an effective training tool."

(2) Since early 2012, FE personnel have used the web version of the Learning Designer – the ***Pedagogical Patterns Collector (PPC)*** – through an LSIS-funded project. From early 2013, the Jisc Advance Projects have been using the PPC for developing, testing and sharing their learning designs – initially involving 6 FE colleges, but with the aim of scaling out to all FE colleges ultimately, through the Jisc Regional Support Centres and their links with key stakeholders in the FE and Skills sector (such as NIACE, AoC, AELP, 157 Group and the Excellence Gateway).

(3) The PPC was used in a BEd course on e-learning at the Faculty of Education of Hong Kong University in 2012 and 2013. In collaboration with Hong Kong University, and funded by ASTRI (Hong Kong Applied Science and Technology Research Institute), the PPC is being redeveloped as a learning design front-end to a Learning Management System that will be deployed to support pedagogically focused e-learning implementation in schools in Hong Kong and China.

(4) The Learning Designer has been adopted for training computer science graduates on an MSc in Educational Technology at the School of Pedagogical & Technological Education (ASPETE) Greece, as part of a project funded by the Greek Ministry of Education; and at the University of Macerata's Faculty of Education in 2012 in a module for trainee teachers to demonstrate the iterative creation of learning designs and lesson plans (see http://buildingcommunityknowledge.wordpress.com/community-of-users/). It was used in a collaborative Open University/IoE MOOC module "Learning Design for the 21st Century" in Spring 2013 with attendance from over 400 people from across the UK HE, FE and community and skills sectors (see http://www.lkl.ac.uk/cms/index.php?option=com_content&task=view&id=559&Itemid=110).

(5) HEIF-funded research with the Camden Partnership for Educational Excellence is further developing the PPC tool. The PPC allows teachers to share and adapt each other's learning designs, and the Swiss Cottage Special School are using it with their partner schools in order to communicate their ideas relating to teaching practice.

(6) Since 2010 the MiGen system has been used at eight schools in the U.K., Israel and Italy. Data has been gathered from more than 300 hours of interaction by 11 to 14-year-olds at four of these schools. Analysis of the data shows that MiGen helps students become aware of a pattern, construct it, and use it as a basis for deriving algebraic rules about its properties. Students interacting with eXpresser over several lessons are able to achieve the learning objectives and to apply their knowledge to other algebraic generalisation tasks. Usage of the TA tools shows that they assist teachers in providing additional support to students.

(7) The MiGen system has been used since 2010 on various Initial Teacher Training programmes at the IoE, such as the Mathematics PGCE and Teach First, as a case study in the use of ICT in mathematics education. When these trainee teachers return to their classrooms, many of them report that using MiGen has changed their way of thinking as to their teaching of algebra and, more generally, on the use of ICT in the classroom.

(8) The UK partner of the Cornerstone project (SRI International and IoE) funded by the Li Ka Shing Foundation has obtained funding of $1,000,000 to develop a suite of four modules aiming to integrate technology into the teaching of maths in around 100 schools in the U.K., and one of these modules is being developed according to the research outcomes of the MiGen project in respect of supporting students' construction and collaboration.

(9) Access to the PPC has been provided to teachers through the Pedagoo teachers' community website since March 2013 (http://www.pedagoo.org/2013/03/building-teaching-knowledge-pedagogical-patterns/). The MiGen team has disseminated materials and findings to teachers and PGCE students through the National Centre for Excellence in the Teaching of Mathematics (NCETM) in professional development events such as the 'Teacher as Researcher' conference in October 2010, the 'Digital Technologies' conference in February 2013, and contributions in the NCETM forum (https://www.ncetm.org.uk/search?q=migen&area=5).

(10) The LDSE and MiGen projects have contributed to the impact arising from the ESRC/EPSRC TEL programme as a whole, particularly as relating to its Personalisation and Productivity themes. An Impact Report from the programme was presented on 13th June 2012 in the House of Lords (*System Upgrade: Realising the Vision for UK Education,* available at http://www.tel.ac.uk/). A Public Event was held in November 2012 at the Royal Society, hosted by the Minister of State for Universities and Science and attended by policy makers, educators and vendors, where the outcomes of the TEL projects were showcased and debated. These outcomes have been discussed regularly since 2011 with the Departments of BIS and Education by Professor Noss (Director of the TEL programme as well as lead PI of the MiGen project) and have informed ministerial announcements on the role of TEL in transforming the school curriculum.

5. Sources to corroborate the impact

Claim (2): Programme Manager at Jisc Advance.
Claim (3): Director of the Centre for Information Technology in Education, University of Hong Kong.
Claim (5): Director of Development & Research, Swiss Cottage School Development & Research Centre.
Claim (6):

- Video "MiGen: Unlocking Algebra" at http://tel.ioe.ac.uk/?page_id=3567 Includes contributions by the Director of Learning (Maths) at Amery Hill School.
- MiGen schools liaison officer, Institute of Education.
- Gutierrez-Santos, S., Mavrikis, M., Geraniou E., Poulovassilis, A. (2012). Usage Scenarios and Evaluation of Teacher Assistance Tools for Exploratory Learning Environments. Available at http://www.dcs.bbk.ac.uk/research/techreps/2012/bbkcs-12-02.pdf

Claim (7): MiGen schools liaison officer, Institute of Education.
Claims (8) and (10): Director of the ESRC/EPSRC TEL Programme; PI on the Cornerstone project.