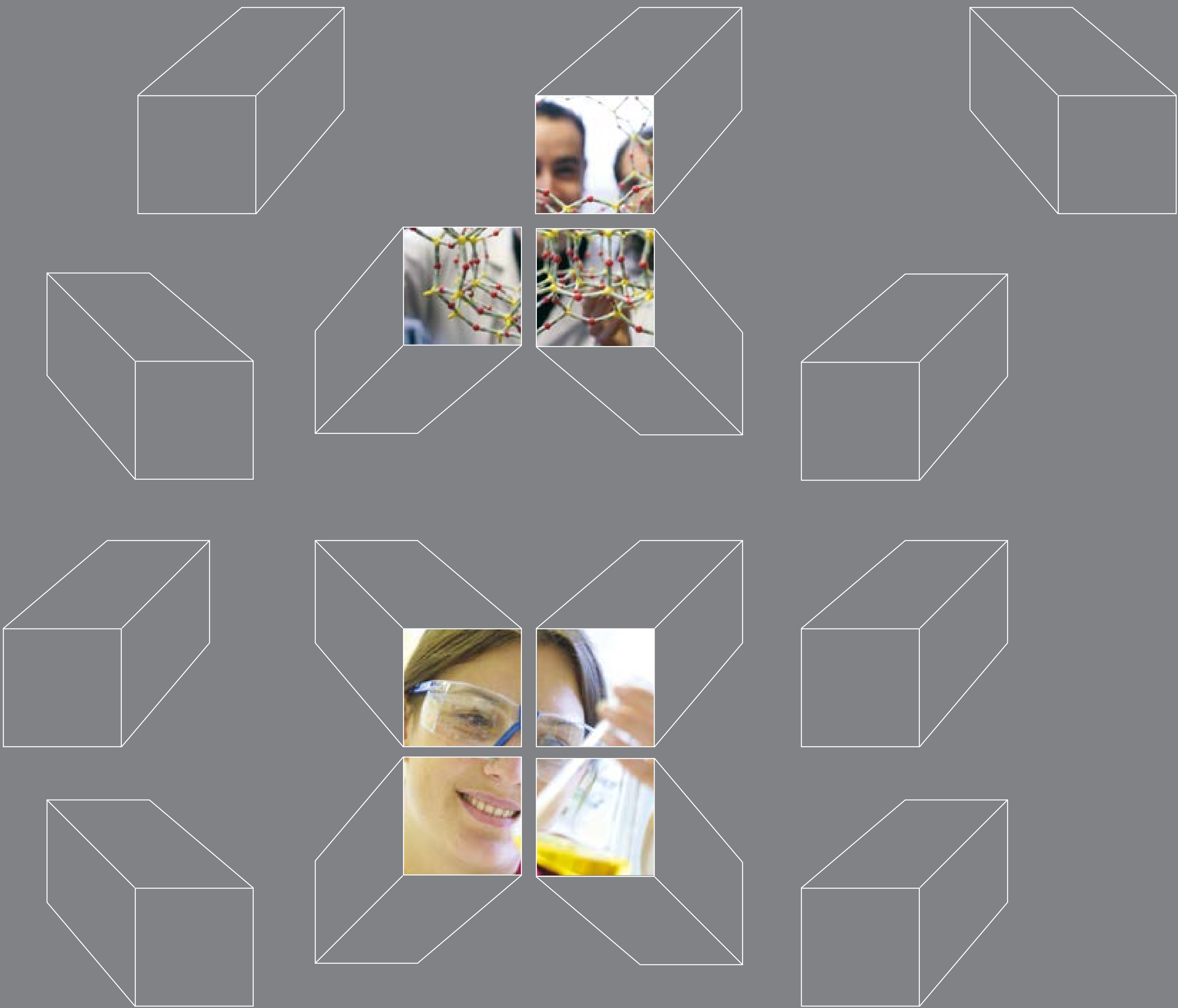
Investigating Longer-Term Curriculum Change and Institutional Impact Within Higher Education

Professor Harry Tolley, Professor David Greatbatch and Dr Helen Mackenzie

December 2012



Investigating Longer-Term Curriculum Change and Institutional Impact Within Higher Education

A report by:

Professor Harry Tolley, Professor David Greatbatch and Dr Helen Mackenzie

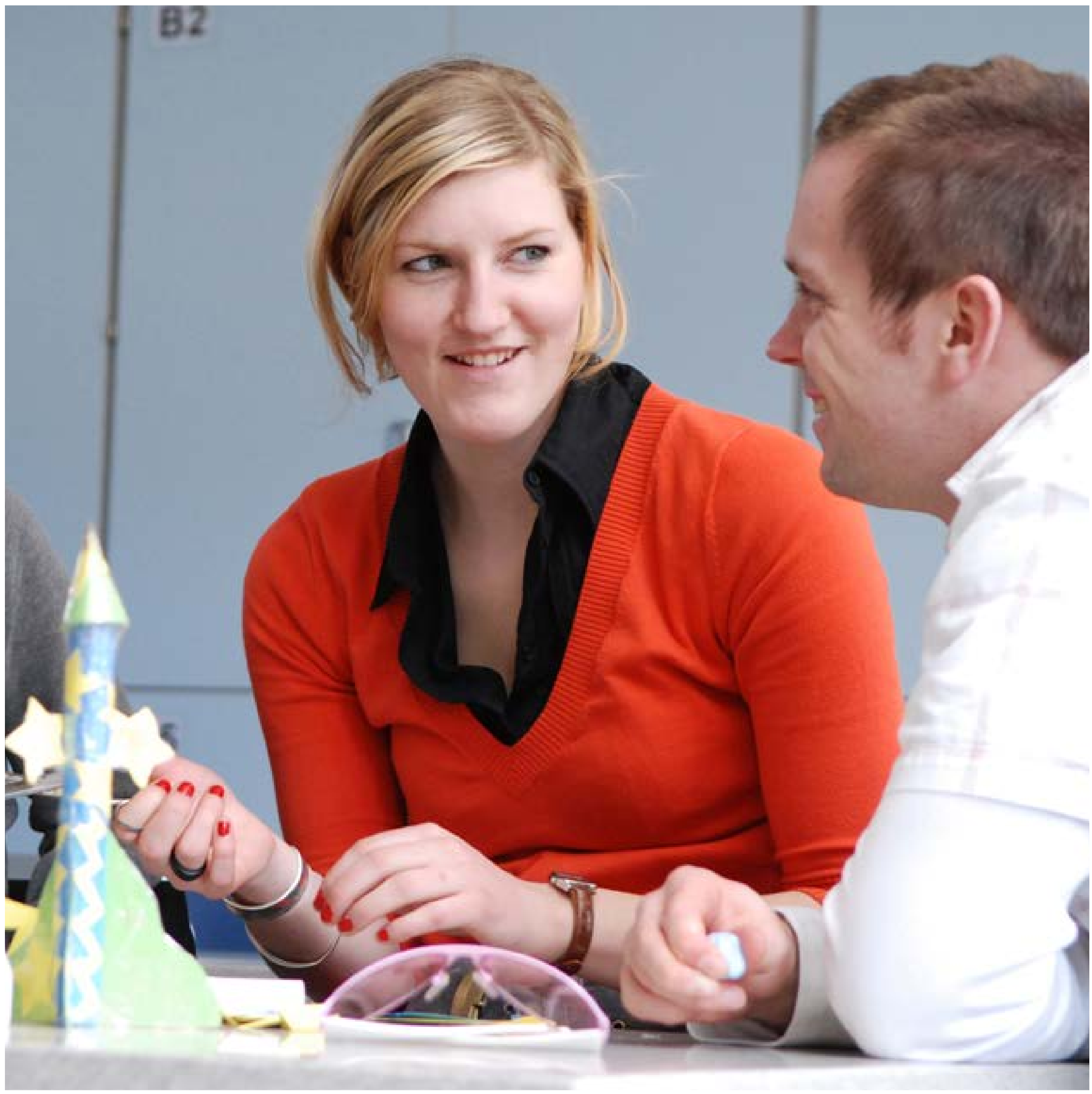
About this document

In September 2011, the National HE STEM Programme identified six priority areas of activity for its final year of operation. One of these areas focused upon capturing the collective learning that emerged from the Programme and its projects in order that it might be further utilised by the higher education sector in the future. This report was commissioned in support of this aim, and sought to explore influencers, enablers and barriers to initiating large-scale curriculum change within UK STEM higher education. This report contains an independent analysis exploring how longer-term curriculum change can become embedded within the higher education STEM sector using the National HE STEM Programme and its projects as its basis. The National HE STEM Programme is grateful to the authors of this report for their hard work and dedication, and to those project leads who contributed by willing sharing a range of information, advice and experiences.

ISBN 978-1-909557-02-4
July 2013

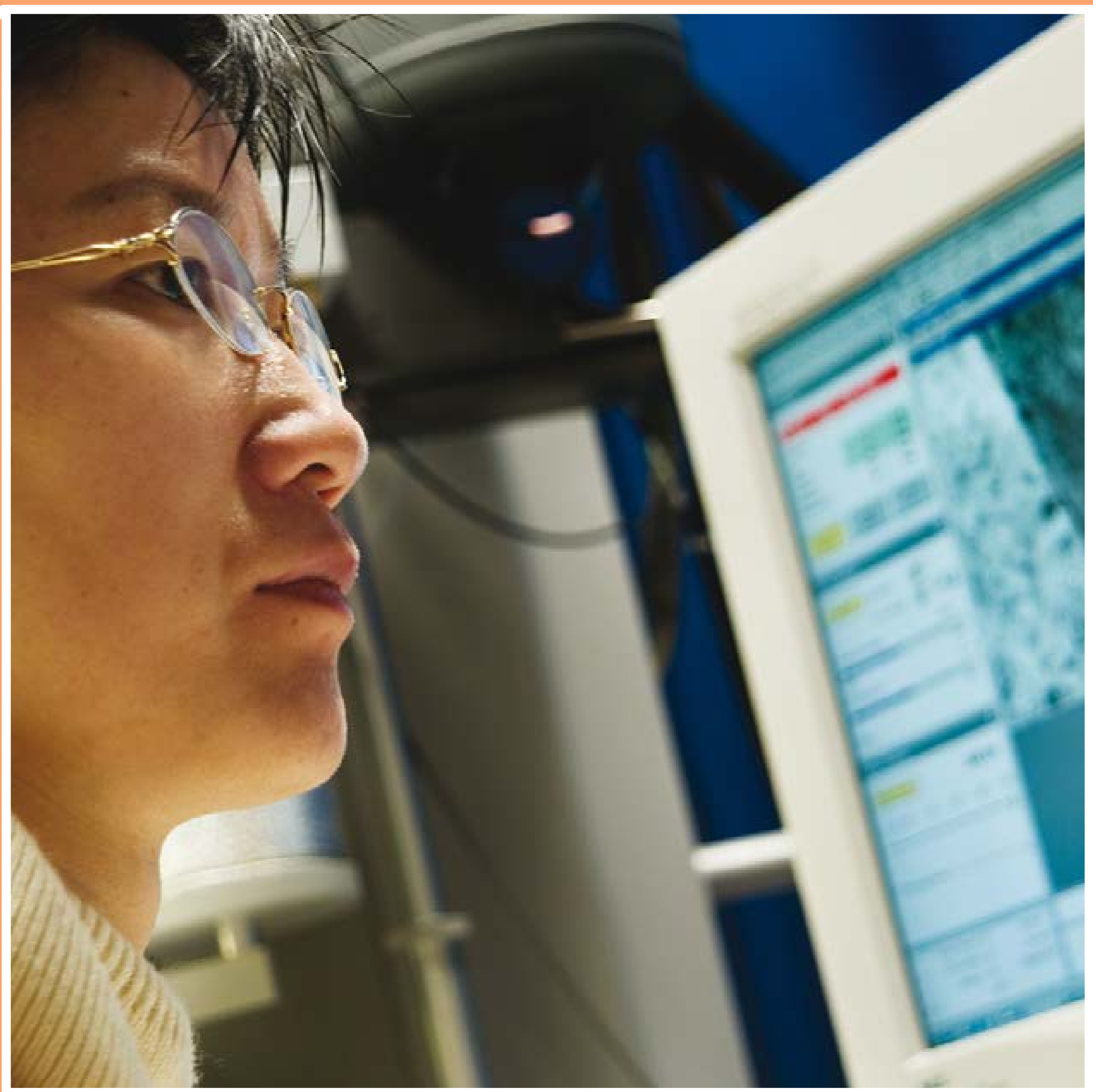
Published by
University of Birmingham STEM Education Centre on behalf of the National HE STEM Programme
University of Birmingham
Edgbaston
Birmingham, B15 2TT
www.hestem.ac.uk

Contents


B2

Abstract

A core area of activity for the National HE STEM Programme has been directed towards facilitating curriculum change. Consequently, the aims of this study were to: develop a better understanding of the factors which bring about large-scale curriculum change that will be sustainable in the longer-term; offer a legacy from the Programme by providing evidence that can be used to inform future decision-making in relation to curriculum change; and, explore how it has helped to change institutional practices within HE. The research began with an investigation into twelve large-scale curriculum enhancement projects followed by the study of four development projects, which sought to build upon the work of discipline-based pilots led earlier by the Royal Society of Chemistry, the Institute of Physics and the Maths, Stats & OR Network. The final phase of the work examined the Programme's impact on institutional practice within four HEIs. Qualitative research methods were used throughout including the analysis of documentary evidence, interviews with key stakeholders and observation at relevant meetings and events. The report offers a synthesis of the conclusions drawn from across all three phases of the investigation and in so doing seeks to address the questions that provided the focus of the research.



1. Executive Summary

Introduction, Terms of Reference and Methodology

1.1 Facilitating large-scale curriculum change in the STEM subjects was a core activity of the National HE STEM Programme. The aim of this research was to investigate the implementation and impact of this work with a view to developing a better understanding of how change of this kind can be achieved, and to examine its potential for sustainability in the longer-term.

1.2 The study was not intended to be a summative evaluation, but to be complementary to the work undertaken by the External Evaluators appointed by HEFCE, and two additional studies commissioned by the National HE STEM Programme itself: one on school-university engagement; and, the other on higher-level skills.

1.3 The terms of reference directed the research towards the: successes of activities with regard to achieving sustainable change; benefits that have emerged of value to those working in the HE sector; factors that have enabled activities to be successful (or otherwise); the impact of activities at different levels; student and staff engagement (particularly senior managers); and sustainability.

1.4 The terms of reference also identified the following sources from which research evidence should be collected: twelve large-scale curriculum enhancement projects; four discipline based development projects; and, four HEIs.

1.5 Qualitative case study methods based upon interviews with key stakeholders were adopted for the research because it was thought that this would enable the research questions to be addressed in an effective manner i.e. of the alternatives would offer the best fitness for purpose. The interviews followed a common structure based on the key research questions, but with the use of prompts and probes for the exploration of issues as they emerged during the interactions. The interview data was supplemented by evidence derived from other sources notable documents such as project proposals, reports and participant observation.

1.6 The research was conducted in three overlapping phases beginning in with large-scale curriculum enhancement projects (mid-February 2012) and concluding with the four HEI case studies in (early August 2012). The key to the implementation of that plan was the negotiation of access via key stakeholders.

National HE STEM Programme: Review of the Background, Context and the Role of Brokerage

1.7 Since the late 1980s the literature shows that HE in the UK has been re-shaped in response to external pressures on the sector such as government interventions and market forces. It is in this wider context that the National HE STEM Programme has been implemented.

1.8 The review of that literature shows how the HE system has been subjected to pressures emanating from socio-economic change in society, the opening up of HE to the market through the introduction of student fees, the application of Computer and Information Technology (C&IT), and professionalising teaching. The response of HE to these forces is reviewed especially with regard to curriculum change.

1.9 STEM refers to the fields of study or disciplines located within science, technology, engineering and mathematics that are regarded as being ‘Strategically Important and Vulnerable Subjects’ (SIVS).

1.10 The Higher Education Funding Council for England (HEFCE) and the Higher Education Funding Council for Wales (HEFCW) funded the National HE STEM Programme in order to further development activities in the STEM subjects across widening participation and higher-level skills themes.

1.11 Between 2005 and 2010 HEFCE had already funded four pilot projects led by professional bodies: ‘Chemistry for Our Future’; ‘Stimulating Physics’; ‘The London Engineering Project’; and, ‘more maths grads’. The aim of the National HE STEM Programme was to take the work of these pilot projects forward in order to create sustainable provision across the HE sector.

1.12 The literature on the role of brokerage in furthering long-term change and institutional impact in HE that has helped to inform the research from a theoretical perspective is reviewed.

Phase 1: Large-Scale curriculum enhancement projects

1.13 Twelve projects were funded with the intention that they would seek to bring about curriculum change in their institutions - not just a module level but within whole programmes of study and across departments.

1.14 The research in this phase was directed towards capturing evidence based on the insights gained by project leads and colleagues who had worked closely with them. Data was collected by means of interviews that were face-to-face wherever possible – the exchanges in three cases being conducted by telephone and email.

1.15 Support from senior managers with the positional authority to facilitate change was identified as being a key factor in successful implementation. Their involvement took three forms: as project leads or team members; practical support by individuals external to the projects (e.g. Heads of School); and, support from those with university-wide responsibilities.

1.16 The timing of projects was a significant factor in acquiring and retaining the support of senior managers. In some cases this was opportune because at the time their aims were closely aligned with the strategic priorities of their departments, whereas in others their progress was disrupted as a result of high-level decision-making driven by institutional imperatives.

1.17 Whilst all of the leads had been involved in innovation in their departments, this was the first experience for some of managing a large externally funded project. Those who had previously directed or managed such projects drew on that experience to act as 'change agents' by successfully brokering innovation within their own institutions and in some cases across the sector.

1.18 Projects depended on the openness and support of colleagues including technicians. It was essential therefore, to ensure that staff were: clear about the benefits of the proposed changes; kept informed about developments; given opportunities to voice opinions; and confident that account was being taken of their concerns.

1.19 Projects generally sought to secure student engagement not simply through representation on planning groups, but by inviting them to become active participants in the development process - to be partners in a joint enterprise rather than consumers of changes planned and delivered by others.

1.20 A number of projects found that the two-year funding period allowed them insufficient time for the systematic planning, implementation, evaluation and dissemination of large-scale curriculum change – especially when this involved internal and external accountability.

1.21 Project leads and teams encountered problems in trying to balance the competing demands on their time of on going commitments to administration, teaching and research with implementing a large externally funded project. This was resolved in a number of cases by the appointment of project officers to take day-to-day responsibility for project management.

1.22 The appointment of external evaluators by some projects introduced an independent perspective (or 'critical friend') to the development process through the provision of formative feedback.

1.23 Two projects involved institutional partnerships from the outset, whereas others were developed during the funding period. The key to successful collaboration rested on partners working together within mutually agreed plans setting out the strategic goals, what actions would be taken, when they would occur, how they would be delivered and by whom.

1.24 Whilst it is still early to evaluate the full impact of the projects it is evident that collectively they have achieved a wide range of positive outcomes including: stimulation of critical reflection about the curriculum; enhanced understanding of student learning needs; new ways of engaging with students; staff development through the experience of managing change; improved team working; and, the development of practitioner networks (or 'communities of practice').

1.25 Since the greatest expense had already been incurred in meeting initial development costs changes that have been embedded into programmes of study will be sustainable out of departmental teaching and learning funds. However, in the absence of external funding it will become difficult to sustain activities such as participation in networks that facilitate the transfer of good practice, and the pedagogic research on which future innovation can be based.

Phase 2: Additional projects

1.26 The aim of the four projects that were the focus of attention in this phase of the research was to build upon the achievements of the HE STEM pilots in Chemistry, Mathematics and Physics run in association with professional bodies.

1.27 The research was again directed towards capturing evidence that would reflect the experiences of stakeholders who had been closely involved in the implementation of the projects. Data was collected by means interviews using a mix of methods including telephone and email, supplemented by evidence derived from other sources including documents and attendance at meetings and other events.

1.28 The four projects differed significantly from each other in respect of: their aims; how they were managed and organized; and, the number of HEIs actively involved in their implementation. Nevertheless, the same generic questions were addressed that had been derived from the overall aims of the research.

4

Context and Problem Based Learning (CPBL)

1.29 In 2006-2009 HEFCE funded 'Chemistry for our Future' - the CPBL project was developed as a way of building on that initiative as part of the RSC's contribution to the National HE STEM Programme.

1.30 The aim of the project is to enhance the undergraduate curriculum through the real-life application of chemical science through the development of a suite of teaching and learning resources in forensics, pharmaceuticals, environmental science and industrial chemistry – all in the form of 5-credit modules that would be easy to incorporate into undergraduate courses.

1.31 The RSC managed and supported the development of those resources by academics from the Chemistry departments at Dublin Institute of Technology, and the University of Leicester that had successfully bid for funding from the programme.

1.32 An action research approach was adopted by the RSC for the development of the CPBL resources, central to which was a systematic approach to quality assurance involving: formative evaluation by the initial developers; piloting in twenty HEIs; and rigorous independent evaluation by an External Evaluator with knowledge and experience of CPBL who was appointed by the RSC.

1.33 The intention is that the CPBL resource units will be disseminated (and their on-going use sustained) by the RSC via its website, events and other activities.

Group Industrial Projects (GIP)

1.34 In 2005-2010 HEFCE funded the 'Supporting Physics' pilot project in association with the IOP. This project was developed as a means of building on that initiative as part of the IOP's contribution to the National HE STEM Programme.

1.35 The aim of the project is to forge close links between Physics departments and employers in order to enhance the undergraduate curriculum with a view to developing the students' employability by working in groups to solve problems set for them by industry.

1.36 The project involved Physics departments from nine universities adopting and developing a scheme that had been run successfully for 20 years as at Durham University, which also provided a manager for the project with experience of GIP methodology. The fact that Durham (widely viewed as a high status institution) was willing to share its experience of GIP was an important factor in encouraging other research-intensive universities to participate in the project.

1.37 The appointment of a project manager (based in a Physics department with long experience of GIP methodology) enabled an overview to be maintained of developments across partner institutions, problems to be identified and addressed in a timely manner, and for support and advice to be provided as and when required.

1.38 The GIP initiative avoided a 'one-size-fits-all' approach; departments being allowed to adapt the GIP to the structures of their undergraduate programmes, especially with regard to their preferred modes of assessment.

1.39 The IOP supported the project by helping universities to work together in order to share ideas and practice, and by disseminating guidance and advice for others wishing to participate. Although initially scheduled to end in June 2012, the IOP has agreed to support the participation of six new departments in the academic year 2012-2013, which means that GIPs have now been introduced into the undergraduate programmes of almost half of the Physics departments in the UK.

Mathematics and Statistics Support

1.40 The **sigma** Mathematics and Statistics Support Network was funded by the Mathematics strand of the National HE STEM Programme through the Institute of Mathematics and its Association (IMA) to enhance the learning of mathematics or statistics of students enrolled on programmes of study at undergraduate or postgraduate levels in any subject discipline – access to such support being non-compulsory.

1.41 The aim of this initiative was to build on the work previously undertaken by the collaborative CETL in the provision of mathematics and statistics support based at Coventry and Loughborough universities during the period 2005-10. Central hubs were established in these two institutions to co-ordinate the activities of the network, along with six regional hubs each of which: appointed a Coordinator; built up membership of the network from local HEIs; hosted events; provided updates for the website; and, attended the network's Annual Conference.

1.42 Experienced practitioners were appointed to act as **sigma** advisors to facilitate the transfer of practice to new centres and to mentor their staff. In 2010 there were just five centres in HEIs offering mathematics and statistics support funded through **sigma**, but by 2012 that number had increased to twenty-two (nine from the 2012 funding round and eight in Wales funded by the Wales Spoke of the National HE STEM Programme).

1.43 Despite the fact that funding for their activities ceased in July 2012, each of the regional hubs has identified mathematics and statistics support practitioners who are willing to take **sigma** network activities forward after that date in order to ensure that they continue to operate as a means of developing and sharing practice. Nevertheless, funding is urgently needed to build on what has already been achieved by the **sigma** network, particularly to support the pedagogic research on which on-going improvements in professional practice can be based.

School Teacher Fellows (STF)

1.44 The STF initiative was conceived at the University of Bristol in 2005; it was then developed by the RSC until 2010 after which the National HE STEM Programme funded it for a further two years. Its aims were closely aligned with those of Chemistry departments and to wider institutional priorities with regard to recruitment as well as to students' transition to HE, retention and employability.

1.45 The project, which continued to be run in association with the RSC, involved qualified and experienced secondary school teachers who already had a PhD qualification, being seconded from schools to work for twelve months in a university Chemistry department. Four STFs were appointed during the two-year life of the project - two in 2010-2011 and two more in 2011-2012.

1.46 Whilst aligning their aims to those of their departments and HEIs, the STFs were given substantial degrees of freedom within supportive environments to generate new ideas for solving problems, take calculated risks and have the self-confidence to initiate and broker change.

1.47 Through their work in university Chemistry departments and outreach activities with schools and colleges, the STFs had a positive impact on students' transition from school to university as evidenced by: the teaching resources, case studies and good practice guides they produced; and, the workshops and other events to which they contributed.

1.48 The RSC website will continue to be a source of information about the issues addressed by the STFs along with the on-line resources they developed - materials that were devised from the outset with a 'long shelf-life' in mind. A 'School Teacher Fellows Project Collaboration Group' has been established that will allow aspects of the work undertaken by the project to be continued.

Phase 3: Four Case Studies in Institutional Impact

1.49 The four universities were selected on the basis of: their involvement with the core activities of the National HE STEM Programme; the evidence that had been collected in them during **Phase 1** and **Phase 2**; the contacts that had been established with key stakeholders; and, the potential they appeared to offer for further investigation.

1.50 The research was directed towards collecting data (primarily by means of interviews) that would draw upon the experiences and insights of those who had been closely involved in (or were in a position to comment on) the implementation, impact and sustainability of activities funded by the programme. Other sources of evidence used included documents and attendance at relevant meetings and events.

National HE STEM Programme at Loughborough University

1.51 The programme funded sixteen projects based at Loughborough – with the university collaborating in another fourteen run in association with partner HEIs. The projects were concentrated in Mathematics and Engineering - thus enabling the momentum established through successive TQE funding streams to be maintained.

1.52 Pedagogic research and scholarly activity in relation to teaching and learning previously undertaken at Loughborough was used as the starting point for the new projects funded by the programme – including those aimed at enhancing the undergraduate curriculum and developing e-learning tools.

1.53 Prior experiences acquired through being the host institution for two CETLs, EngSC, and a range of FDTL and JISC activities had enriched its 'human capital' giving it the ability to support externally-funded projects by providing help with: bid writing; planning; management; evaluation; report writing; and, training student mentors.

1.54 The university was also able to draw upon the 'network capital' of individuals, schools and centres to 'broker' collaborative partnerships and the development of 'communities of practice' both within the university and across the HE sector – thus adding value to the activities funded by the programme.

1.55 The projects based at Loughborough were able to build upon approaches to student engagement that had been established previously (e.g. by the two CETLs and EngSC) and to do so within the policy framework provided by the university's 'Enhancing Student Engagement' initiative.

1.56 The management structures and procedures provided an environment within which the efforts and achievements of those who had successfully bid for funding and engaged in scholarly activity were valued and supported, and in which mechanisms were in place so that their efforts could be recognised and rewarded.

National HE STEM Programme at the University of Leeds

1.57 The programme funded a range of activities based at this university including two in Chemistry, two in Engineering and six in Mathematics – though it should be noted that 'Mathematical Modelling and Problem Solving' and 'Enhancing Maths Support' were seeking to enhance student learning across a wide range of subjects.

1.58 The timing of the funding opportunities the programme provided coincided with reviews of the curriculum, which indicated that change was needed to improve students' transition to HE and employability. Support was forthcoming therefore, from students, staff and senior management for the changes that were initiated.

1.59 The culture in the departments in which projects funded by the programme were based encourages continuous improvement through curriculum innovation and sharing best practice. This is facilitated by organisational structures that encourage the discussion and exchange of ideas via networks of practitioners both within the STEM disciplines and across the university as a whole.

1.60 The aims of the curriculum enhancement projects investigated by this research were closely aligned to the goals of their schools and to those of the university with regard to the students' experiences and especially their future employability. The emphasis on practical problem solving that was in evidence was part of a wider shift towards producing STEM subject graduates who are very well prepared for entry to the workplace.

1.61 The development activities initiated by the projects studied for the purposes of this enquiry were based on the outcomes of prior research directed towards eliciting a deeper understanding of the problems they were seeking to address. This not only provided the evidence on which changes to teaching and learning could be based, but also helped to build engagement with employers, staff and students.

1.62 The implementation of the projects funded by the programme and the impact they achieved benefited from the close involvement of staff capable of acting as 'change agents' i.e. individuals with: a clear sense of purpose; a commitment to curriculum improvement; the ability to work collaboratively with others; strong links to those in positions of authority; and, good personal networks.

1.63 The initiatives funded by the programme in the university were encouraged to flourish by a culture in which high levels of achievement in relation to teaching and learning are recognised and rewarded as evidenced by the fact that the lead for two of its projects has been made University Teacher Fellows.

National HE STEM Programme at the University of Leicester

1.64 The programme funded fifteen research and development initiatives at the University of Leicester distributed across the full range of STEM disciplines as follows: Engineering (2); Physics (4); Chemistry (7); and, Mathematics (2).

1.65 The intended outcomes of the activities funded by the programme were consistently aligned with the strategic goals of the College in which they were based, and to priorities of the university with regard to students' transition to HE, retention, achievement and future employability.

1.66 The reorganization of the university to a collegiate system not only encouraged the development of inter- and multi-disciplinary approaches to the design of programmes of study and research, but also the transfer of ideas and resources relating to teaching and learning - especially with regard to problem based learning (PBL).

1.67 Earlier TQE funding streams left the university with a legacy - especially in Chemistry and Physics – of the accumulated knowledge and experience held by individuals and groups with regard to pedagogy and, the planning and management of curriculum change. This, along with the networks or 'communities of practice' that had been established, contributed to the development of an institutional culture within which the projects funded by the Programme could achieve their intended outcomes.

1.68 Successful partnerships were brokered between projects based at the university with professional bodies, an IT software provider, industrial organisations, and other HEIs. The collaboration resulting from these partnerships helped to facilitate the successful implementation of planned changes to the curriculum, the impact achieved by those development activities, and their on-going sustainability.

1.69 The status of teaching and learning is being raised within the university and its importance has been recognised by the rewards given to staff for outstanding contributions - two of the leads of projects funded by Programme having been made University Teacher Fellows in 2012.

National HE STEM Programme at Sheffield Hallam University

1.70 The National HE STEM Programme funded fourteen projects at Sheffield Hallam University which were distributed by subjects as follows: Mathematics (4); Engineering (4); Chemistry (1); and across the STEM disciplines (5). University academics led nine of those projects, whilst five projects were led by non-academic staff based in 'Women in Science, Engineering and Technology', 'Student and Learning Services', and the 'Secondary Science ITE' team.

1.71 The long-standing commitment of the university's senior managers to activities designed to enhance teaching and learning created a culture, which encouraged staff to bid successfully for funding from the Programme. The aims of all of the projects it funded were closely aligned with institutional goals and enjoyed high-levels of senior management support throughout.

1.72 Many of those who applied for funding were already engaged in on-going activities related to the university's key strategic priorities - the National HE STEM Programme being viewed as a means of further developing and consolidating those initiatives. The projects were able therefore, to build on the legacy inherited from previous investments made possible by successive TQE funding streams.

Conclusions

1.73 This final chapter of the report offers a synthesis of the conclusions drawn from across all three phases of the investigation, and in so doing seeks to address the key questions that provided the focus of the research.

1.74 In reaching these conclusions theoretical constructs drawn from the literature on change in the HE sector were used to connect the issues that emerged from the research to the wider thinking about educational change in HE. It also provided a series of 'lenses' through which to examine qualitative data that had been collected. Constructs found to be useful were: the idea of society moving to a 'liquid' stage of modernity; the 'ecological university'; 'intellectual capital'; 'brokerage'; 'change agency'; and, 'communities of practice'.

1.75 In discussing the conclusions, reference has been made where appropriate to the impact on, and implications for, the HE system of social, economic and political changes in its external operating environment.

1.76 Evidence drawn from across all three phases of the research shows that the intended outcomes of the projects and initiatives funded by the programme were clearly defined, demonstrated a strong sense of purpose and as such were in close alignment with the goals and policy priorities of the institutions in which they were located.

1.77 Given the importance now attached to students' transition to HE as expected many of the activities funded by the programme were directed towards reaching a better understanding of how the 16-19 curriculum is defined, transacted and assessed as well as seeking to: build improved relationships with schools, colleges and employers; and, to enhance the experiences of students once they have entered university. The model that was developed and piloted by the STF project for Chemistry could be applied equally well to other STEM subject disciplines as well as in institutions across the sector.

1.78 The projects funded by the programme provided evidence of a discernible shift in pedagogy towards problem based learning and group project work allied to stronger links with industry. Changes such as these to the curriculum of the STEM disciplines are indicative of a general movement in HE towards what has be described as a 'pedagogy for uncertain times'. In addition to helping students to further their future employability, the emphasis is on encouraging them to become Mathematicians, Chemists, Physicists, or as one stakeholder put it a 'passionate engineer'.

1.79 The hope is expressed that funding can be found to: further develop and disseminate the approaches to teaching and learning developed in the STEM disciplines; and, for the evaluations studies and pedagogic research that would provide the knowledge and understanding on which future curriculum innovation can be based.

1.80 The changes in teaching and learning that were discerned are not the product of top-down management-led reforms, but the result of actions taken by individuals and groups with an awareness of the need for change combined with the ability to draw on their 'innovation capital' in order to create and implement imaginative solutions to problems relating to the curriculum.

1.81 The support received by projects from senior managers was a key factor in successful implementation, especially when project leads and their teams were seeking to: obtain additional funding; secure 'buy-in' from internal and external partners; implement planned changes within short time scales; expedite high level decision-making; and, deal with unexpected problems.

1.82 Senior managers operating at the highest level were responsible for the leadership that created the institutional frameworks within which projects could flourish, including determining the strategic priorities with regard to the curriculum and creating the cultures within which teaching and learning is valued and where outstanding contributions to its improvement can be recognised and rewarded.

1.83 Project leads (in association with senior managers) need to ensure that their colleagues (including technical and other support staff) are: clear about the benefits of proposed changes; kept fully-informed about developments; able to access evaluation data; given opportunities suggest ideas/ voice their opinions; able to discuss problems and how to overcome them; confident that their concerns are being taken into account; and, fully involved in planning and implementation.

1.84 Participation in the development activities associated with projects provided both individuals and groups with opportunities to work within 'communities of practice' and in so doing further their professional development with regard to improving their skills in: bid writing; project planning and management; report writing; evaluation; and, dissemination. This enhanced 'human capital' is part of the Programme's legacy.

1.85 Research shows that students can respond negatively, not just to their experiences in relation to their learning, but also to HEI structures and processes. Some projects sought to obviate this by inviting students to become active participants in the development process i.e. to collaborate with the team in a joint enterprise rather than to be passive consumers of changes planned and delivered by others. Work undertaken in relation to student engagement and learning support are part of the Programme's legacy from which the whole HE sector can learn. However, there is an urgent need for qualitative research to further our understanding of the nature, function and quality of student engagement with curriculum development and educational change.

1.86 Projects leads had varying degrees of experience in such a role – for some this being their first experience of managing an externally funded initiative. In the face of coping with new demands the support of senior management was especially important in their case - a number of them having been the recipients of mentoring by more experienced colleagues. They would also have benefited from formal assistance on project management such as that offered earlier in the guidelines provided by the FDTL.

1.87 By way of contrast, some project leads had previous experience of directing externally funded projects including those supported by the FDTL and TQEF initiatives. They proved themselves to be capable of acting as 'change agents' by successfully brokering innovation not only in their own institutions, but across the HE sector. Their departments and universities will doubtless continue to benefit from their ability to broker change; and, hopefully the means will be found for others to gain from access to their expertise.

1.88 Many of the projects involved HEIs working in partnerships – sometimes in association with a professional body (e.g. IOP, MSOR and RSC). This collaboration helped to further the development process, facilitate practice transfer and advance professional learning. The success of these partnerships rested on an agreement to work within a common framework for the management of their projects in the form of mutually agreed operational plans. Such plans enabled activities to be coordinated across partner institutions, and helped to counteract problems such as misunderstanding in relation to roles and responsibilities.

1.89 Despite the view held by some stakeholders *'that the best is yet to come'* with the regard to the impact of activities funded by the programme, there was broad agreement that the following outcomes had been achieved: much critical reflection about teaching and learning; enhanced understandings of student learning needs for life and work in a 'liquid age'; new ways of engaging with students and supporting their learning; improved feedback to learners; opportunities for staff development; wikis that offers ideas and advice; improved team working in relation to curriculum design and delivery; and, practitioner networks (or 'communities of practice') within institutions and across the HE sector.

1.90 Despite recognising that the HE sector is facing an uncertain future economically, the stakeholders questioned were generally optimistic about the sustainability of what had been achieved by their projects on the grounds that: the greatest expense had been incurred in meeting the initial development costs; changes have been embedded into programmes of study and can now be sustained out of departmental teaching and learning funds; and, senior management, staff and students will continue to provide their on-going support – as will professional bodies such as the IOP, MSOR and RSC. However, in the absence of new sources of funding it will be more difficult to sustain participation in the activities of professional networks and the pedagogic research on which future developments can be based.

1.91 The research identified some notable examples of projects in which evaluation had played an important role in providing evidence of impact and furthering the development process. However, evaluation could have been used more widely and effectively had its role been better understood and its potential recognised. It is argued that project evaluation could be improved with the help of tools like RUFDATA (Saunders, 2000), which were widely used to good effect during earlier TQE funding streams.

2. Introduction, Terms of Reference and Methodology

Introduction

2.1 In March 2012 the National HE STEM Programme Hub at the University of Birmingham commissioned a small team consisting of Professor Harry Tolley, Professor David Greatbatch and Dr Helen Mackenzie to conduct research into one of its core areas of activity - facilitating large-scale change in the HE STEM curriculum. The overall intention was explore the implementation and impact of this work with a view to developing a better understanding of the factors that are necessary for change of this kind to be achieved, and to examine its potential for sustainability in the longer-term.

2.2 The primary aim of the research is to offer a contribution to the legacy left by the National HE STEM Programme that will help to further the process of curriculum change, by providing evidence that can be used to inform future decision-making with regard to both policy and professional practice. It is anticipated therefore that this report will be used to:

- Articulate the impact of the Programme and the sustainability of its activities to the Higher Education Funding Councils for England and Wales.
- Inform future strategies for initiating changes in learning and teaching at a policy/funder level.
- Support development activity by practitioners and their senior managers, in particular those undertaking curriculum change within HEIs.

The structure of the report

2.3 **Chapter 3** provides a contextual overview of National HE STEM Programme and a brief description of its core activities. Although the policy context has changed significantly since its inception in 2010, it is argued that the impact of its actions can only be judged against the background of what was already in place as a result of prior Teaching Quality Enhancement Funding (TQEF) initiatives across the whole HE sector in general and in relation to the STEM subjects in particular. Ideas drawn from the literature that helped to inform the research from a theoretical perspective are reviewed.

2.4 **Chapter 4** discusses of the funding strategy with regard to the twelve large-scale curriculum enhancement projects, provides an overview of those projects, gives an account of the methods used in the collection, processing and analysis of the research data and sets out the key findings that emerged from the initial phase of the investigation.

2.5 **Chapter 5** examines the strategy with regard to the funding of the four large-scale development projects studied in this phase of the research (i.e. to build upon the legacy of pilot activities established through previous funding initiatives). It then provides an overview of the four projects, gives an account of the methods used in the collection, processing and analysis of the research data and sets out the key findings on a project-by-project basis, generic conclusions drawn from across all four projects being offered in **Chapter 7**.

2.6 **Chapter 6** provides a rationale for the selection of the four HEIs and an overview of the methods used in the collection, processing and analysis of research data. The outcomes are discussed on a case-by-case basis, generic conclusions drawn from across all four of the HEIs being offered in **Chapter 7**.

2.7 **Chapter 7** summarises the main conclusions drawn from across all three phases of the investigation.

Terms of reference

2.8 The terms of reference made it clear that the purpose of the study was not to conduct a summative evaluation, but that it would be complementary to the work undertaken by the External Evaluators appointed by HEFCE, and to two additional studies commissioned by the National HE STEM Programme itself: one on school-university engagement (led by Martin Hollins); and, the other on higher-level skills (conducted by Jane Kettle and Judy Smith).

2.9 The terms of reference listed a set of research questions and related sub-questions, which served to focus the research on the following topic areas: the key successes of HE-led activities with a particular emphasis on achieving sustainable curriculum change; the benefits emerging from this work that participants within the HE sector particularly value; the factors that have enabled activities to be successful (or otherwise); the impact at module, programme, departmental, faculty or whole institution levels; the extent to which staff (particularly senior managers) within HEIs have been engaged in the activity; the plans that exist in relation to the innovation including how it will be supported in future and how the learning will be utilised more widely;

and, the value of the work of the National HE STEM Programme within the HE sector.

Location of the research

2.10 The terms of reference identified twelve large-scale curriculum enhancement projects along with four development projects that had been funded by the National HE STEM Programme on which the study should be based i.e. the sources from which the evidence should be derived. Typically, the former were in receipt of funding in the order of £30k each and were based upon a single university – though many have worked in collaboration with employers or in partnership with other institutions in the HE sector. On the other hand, the latter were more complex and extensive in scale as reflected in their funding, the number of HEIs involved in each case and their association with the professional bodies (Royal Society of Chemistry or RSC, the Institute of Physics or IOP and the Maths, Stats & OR Network or MSOR), which had previously been responsible for leading the discipline-based pilot projects on which they were based.

2.11 In addition to the above curriculum enhancement projects, the researchers were asked to explore the impact that work initiated through funding provided by the National HE STEM Programme has had on changing institutional practices within a selected number of HEIs - especially in terms of how teaching and learning within the STEM disciplines is designed and delivered. An initial list of ten HEIs was selected on the basis of the range and depth of involvement with the Programme's core activities. Ultimately, this was narrowed down to four: Loughborough University; Sheffield Hallam University; University of Leeds; and, the University of Leicester. A number of factors were taken into consideration in reaching that decision including: the National HE STEM Programme-funded activities located within those HEIs; the amount of data that had already been collected there in **Phase 1** and **Phase 2** (and hence not only how much was already known but the personal contacts that had been established with key stakeholders); the contrasts between the four universities as HEIs; and, the potential they appeared to offer for further investigation.

Research methods

2.12 Given the aims of the research (paragraph 2.2) it was essential to address the research questions effectively and in a rigorous manner i.e. that the research design should be determined by the notion of 'fitness for purpose' (Cohen et al., 2000, p.73). A qualitative case study approach was adopted therefore, because it was thought that the methodology would best meet that criterion. Whilst case studies frequently involve quantitative methods (e.g. Yin, 1994) advocates the use of both qualitative and quantitative), a qualitative approach is most likely to provide a deeper understanding of the case(s) (Merriam, 1998). Creswell (1998) showed that a case study might be defined in different ways - Merriam considering it to be a methodology, whereas Stake (1995) regards it as a choice of what is to be studied. However, whilst there are these different perspectives, it is clear that the focus of the research is upon the case(s). In defining the cases for this study it was decided that each overarching National HE STEM Programme research theme would form a 'case'. Each research phase (1-3) therefore, includes different case studies as follows: **Phase 1** of the data collection involved twelve 'Large-scale Curriculum Innovation and Enhancement'; **Phase 2** included four development projects ('Context and Problem Based Learning', 'Group Industrial Projects', 'Maths Support' and 'School Teacher Fellows'); and, **Phase 3** the examination of the impact of National HE STEM Programme projects on four HEIs (Loughborough University, University of Leeds, University of Leicester and Sheffield Hallam University).

2.13 A case study is distinctive because it is regarded as a 'bounded system' (Stake, 1995: 2). This draws attention to a case as having a boundary and working parts, creating an integrated system. Stake argued that *'people and programmes are clearly prospective cases'* (p.2). Therefore, for the purposes of this study, as indicated above, the different cases are bounded by the focal point of the inquiry. In addition, the individuals involved in conducting the different development projects also fit the definition of a case, thus facilitating the notion of investigating an integrated working system. This study takes the view therefore, that each case consists of two levels with one nested in the other, which allows multi-level investigation and analysis. The outer level encompasses the focal point of each National HE STEM Programme Project at each of three research phases; whereas, the inner level includes those working on individual projects, including the key stakeholders. It is also important to highlight the fact that the cases are also bounded by: discipline (Chemistry, Mathematics, Engineering and Physics); time (the various projects were conducted over a specified period of time); and, place (the projects were undertaken within different Schools, Faculties and HEIs). Whilst a case can be a single instance or subject of study, a number of cases can also be studied, and when this is done it is said to be a 'collective' case study (Stake, 1995: 5). The selection of multiple cases is commonly used as a strategy for enhancing the confidence of the findings (Miles and Huberman, 1994) making it particularly relevant to this research. By using a collective case study approach where the focus is upon the particular, it was thought that a fuller understanding would be gained of the different National HE STEM funding streams and their projects. In addition, it would facilitate multi-level analysis where points of convergence and difference could be discerned.

2.14 In making these strategic decisions about the research methodology it was also important to recognise that the interest in the chosen cases may vary, and that it can be either intrinsic or instrumental (Stake, 1995). An intrinsic case study involves an interest in a specific case because of its uniqueness in illustrating a particular trait or problem e.g. it could be a module, a programme of study or a whole curriculum design. In contrast, an instrumental case study involves the case being of secondary importance because it is identified to illustrate a particular issue (e.g. the students' experience) enabling the researcher to gain a deeper understanding of matters relating to that issue. It is the former of these two alternatives that corresponds closest to the aims of this study because it is the examination of the uniqueness of the different National HE STEM Programme initiatives that is at the core of the investigation.

2.15 Typically then, a case study is a detailed, in-depth and holistic investigation into a specific phenomenon (Creswell, 1998). In order to achieve that aim in relation to this research, the data collection was conducted over a period of time (Bryman, 2004) involving three distinct phases (see paragraph 2.12). That data collection incorporated multiple sources of information that was rich in context, including: participant observation, semi-structured interviews (face-to-face and remotely by telephone and email) and various forms of documentation/text. This was consistent with the suggestion by Gillham (2000) that the heart of case study methodology is *'the collection and study of multiple forms of evidence, in sufficient detail to achieve understanding'* (p.19). A key advantage of taking this approach was that it could be used for the purposes of triangulation, a term originally taken from surveying (Stake, 1995) involving the pinpointing of a location by the use of a number of different 'measurements' taken from different angles of vision. It was thought that by adopting this approach, information could be corroborated and if they converged the confidence would be increased that the different sources were shedding light on a particular theme or perspective. This also increases the trustworthiness of the outcomes of the case study (Creswell, 1998; Miles and Huberman, 1994; Cohen et al., 2000). Thus, triangulation is a key aspect of the case study approach, and to that end multiple methods of data collection have been used in this research.

2.16 Thus far the focus has been on positive aspects of a qualitative case study design, but it is also important to acknowledge its inherent limitations. The key concern when conducting qualitative case study research, especially a single case, is that of the external validity, or generalisability of the cases (see Silverman, 2005; Bryman, 2004; and, Bassey, 1999). This relates to the extent to which a finding in one setting can be applied more generally. Part of the problem lies in thinking about generalisability in the same way as scientific or statistical generalisation (ibid.) as illustrated by Arber (1993) when writing about quantitative research, *'the purpose of sampling is usually to study a representative subsection of a precisely defined population in order to make inferences about the whole population'* (p.38). But the problem is, *'how do we know [...] how representative case study findings are of all the members of the population from which the case study was selected?'* (Bryman, 2004:51). This has led some commentators to view generalisation as an unessential outcome of case study research (Bassey, 1999). For example, Stake (1995) agrees with many critics that qualitative methods cannot claim confidently to generalise from a case, but he also argues that it is possible to use a process he developed with Deborah Trubull called *'naturalistic generalisation'* (p.20). This involves knowledge about the cases, which could be for example individuals, being transferred from the researcher to the reader through the rich, descriptive narrative report. Therefore, it is the reader who decides if findings from one study can be taken and applied to a similar situation. Hence, the emphasis is upon the transferability of the outcomes, as opposed to their generalisability. Similarly, Bassey (1999) put forward the use of *'fuzzy generalisations'* (p.46) as an alternative to those derived from statistics. Fuzzy generalisations are based more upon the idea that predictions arising within the empirical findings state that something might happen, but they do not provide a measure of probability. Thus, fuzzy generalisations carry *'the idea of possibility, but no certainty'* (ibid: 46). Therefore this study does not claim that the empirical findings are generalisable in the same way as statistical or scientific traditions, with such a small sample it would be meaningless; rather it is aligned with the alternative approaches put forward above.

2.17 Interviews are commonly used for the purposes of data collection in research in the HE sector (Tight, 2003), and they are frequently used in small-scale educational research (Drever, 1995). They were used as a key data collection instrument in this research because they presented the most direct way of asking university staff and other key stakeholders about their personal experiences of individual projects, and an effective mean therefore of addressing the main research questions. As pointed out by Kvale and Brinkmann (2009): *'if you want to know how people understand their world and their lives, why not talk to them? Conversation is a basic mode of human interaction...Through conversations we get to know other people, learn about their experiences, feelings and attitudes, and the world they live in'*. (p.xvii) Hence, because the overall aim of the research interviews was to provide individuals with the opportunity to talk in detail about their National HE STEM Programme projects and experiences, it was decided that they should be semi-structured. It was necessary therefore, to plan the general structure of the interview in advance and to determine the main questions that would be asked. The detailed structure of the interview was then worked out during the interview where the individuals were provided with opportunities to construct answers at length in their own words to a series of pre-determined open-ended questions. The researcher then responded using prompts that facilitated broader coverage of a question, and probes aimed at exploring answers in greater depth (Drever, 1995). In this interviewer role, each researcher took on elements of two metaphorical interviewers (Kvale and Brinkmann, 2009) i.e. a 'miner' and a 'traveler' (p.48). Firstly the miner interviewer unearths nuggets of knowledge out of the interviewee's comments. This is done through the use of probing questions, which avoid asking leading questions. The second metaphorical interviewer is a traveler on a journey to a distant land in which prompts and open-ended questions allow unknown territory to be explored, where those being questioned are encouraged to talk about their world and experiences. The traveler (researcher) then returns with a narrative account to analyse and share.

2.18 The interview structure outlined above was translated into a guide that included both a thematic and a dynamic dimension (Kvale and Brinkmann, 2009). It was thematic in that it addressed the key research questions in an attempt to unearth 'nuggets' of knowledge about e.g. planning, intended outcomes, implementation, impact, sustainability, and factors promoting success. At the same time it was dynamic in that it was designed to promote good interaction during the interviews through the use of prompts and probes allowing the exploration of emergent issues. Although this basic structure was adhered to throughout all three phases of data collection, it was 'customised' according to the case study under investigation. A generic interview guide showing the key questions and themes addressed is shown in **Appendix 1**. During the data collection phases every effort was made to conduct the interviews face-to-face. Nevertheless, circumstances were such that a small number of interviews had to be conducted by telephone (supplemented as necessary by the exchange of emails).

2.19 The examination of various forms of text is a method of data collection that is frequently used by qualitative case study researchers as part of a multiple method approach (see Stake, 1995; Merriam, 1998; Creswell, 1998; Gillham, 2000). The key advantage to be gained through the use of documentation is that the presence of the researcher does not intrude into or alter the setting in any way, plus it provides easily accessible sources of information that can be used for the purposes of triangulation (Merriam, 1998). Consequently, the research team examined a range of documentary evidence made available by the National HE STEM Programme via an electronic 'drop box' including project proposals and reports. This enabled the researchers to gain a deeper knowledge and understanding of individual projects and to cusomise the generic interview guide, as indicated in paragraph 2.18. Additional material was accessed via the HE STEM Programme website and from those of partner institutions (RSC, IOP, the MSOR and the Royal Academy of Engineering or RAE). This facilitated the examination of the different STEM projects from alternative perspectives. In addition, documents such as conference papers and journal articles were made available during events such as seminars, attendance at which enabled a further research method to be employed as discussed below.

2.20 Participant observation involves the researcher being immersed in a group over a period of time, observing behaviour, listening to what is said in conversations between others and asking questions as and when it is judged to be appropriate e.g. to seek clarification or exemplification of something that has already been said (Bryman, 2004). Of late, ethnography has become the preferred term for use in context such as these as opposed to participant observation. However, for the purposes of this study the latter is considered to be more appropriate because the emphasis in the research has been on the collection of data by means of interviews and the examination of documents with observation playing a much smaller, yet significant role. It was deployed whenever unplanned opportunities arose to use it during the research including invitations to attend seminars, symposia, team meetings and network conferences.

Managing the process

2.21 As indicated in paragraphs 2.10 and 2.11 the focus of the research was on: twelve large-scale curriculum enhancement projects some involving partnerships between HEIs; four large scale development projects each of which was associated with a professional body and had multiple partners that were widely distributed geographically; and, the impact of National HE STEM Programme-funded activities on four HEIs. The work commenced in mid-February 2012 and continued through until August 2012 – though the related data analysis and report writing was not completed until after that date. At the outset the intention was to conduct the research in three overlapping phases beginning in **Phase 1** with the deskwork and data collection, processing and analysis relating to the twelve large-scale curriculum projects[1]. When that was well underway (i.e. by mid-April) work on **Phase 2** would be initiated, the preliminary deskwork being followed by data collection, processing and analysis in connection with the four large-scale discipline-based development projects. Work on the four HEIs case studies would be on going throughout - though in the early stages it would be relatively low key gaining in intensity over time as the work on both sets of development projects began to ease. The original intention was that that the deskwork and fieldwork relating to **Phase 3** would be completed by mid-July at the latest, but in the event the practical difficulties of arranging interviews at a busy time of the academic year meant that the work was extended into August.

2.22 The key to implementation of that action plan was the negotiation of access – a process that involved: making initial contact with key stakeholders across all three phases of the study; explaining the aims of the research; securing agreement with regard to their willingness to engage with the researchers; seeking guidance on relevant documentation; identifying other stakeholders; and, agreeing dates and times for meetings and/or interviews. That process began with an email message from the Programme Director to all key stakeholders explaining the purposes of the investigation, introducing the research team and asking for their support. That was followed by an email message from the research team to each named stakeholder setting out in more detail how it would like to proceed with the enquiry particularly with regard to its interactions with them personally via a lead researcher. From that point on that named member of the team was responsible for building the relationship with key stakeholders and their colleagues and collecting data from and through them. Throughout the entire process the researchers made explicit how they intended to use the data they had collected for the sole purposes of reporting to the National HE STEM Programme, and gave those being questioned opportunities to discuss how that data would be stored and analysed. Interactions were only recorded with the prior agreement of those being interviewed otherwise the researchers relied on their field notes the details of which were checked by email or telephone on some occasions. Whilst acknowledging the support given to the research by named individuals they are only referred to by their job roles whenever they are cited in the text.

1 The decision to begin the research with the large-scale curriculum enhancement projects was based on the fact that contact had already been with Project Leads at events run for them by the National HE STEM Programme.

3. National HE STEM Programme: Review of the Background, Context and the Role of Brokerage

Introduction

3.1 According to Bauman (2000) society has moved from a 'solid' phase of modernity to a 'liquid' modern age (p.1). A characteristic of this age is that social frames and institutions are fluid and open to change with their shape altering more rapidly than the time taken to cast and solidify them. Society therefore, is subject to constant and complex change in which people, institutions and organizations are increasingly in a state of transition (Field et al., 2009). Set in this context, HE in the UK has already gone through a period of rapid change. In fact, since the end of the 1980s it has been re-shaped mainly in response to external, or 'top-down' challenges, as a result of government interventions and market forces. Jackson (2002) has suggested that much of the change in HE is a response to one or more external pressures. The key challenges and forces he identified have been summarized below on the grounds that this will provide insights into the wider context in which the National HE STEM Programme has operated.

Wider context

3.2 Socio-economic change it is argued created a demand for: greater opportunities for learning in HE; an increase in the number of entrants from previously under-represented groups; matters relating to equality and opportunity to be addressed; and, for students to be viewed as 'consumers' with rights and entitlements such as being consulted about the design and delivery of their courses. It has been driven by the implementation of government policies aimed at widening participation, and by the expansion of funding councils. The HE response has resulted in a fundamental change - the move from an elite system, to a mass system to which at least 40% of the population has access (Scott, 1995). Consequently, the student population has become increasingly diverse in terms of: age on entry; previous experiences; qualifications; socio-economic status; ethnicity; and, cultural background. This has been facilitated by: the creation of new routes into HE (e.g. access courses and Foundation Degrees); modularisation of the HE curriculum; re-structuring the academic year into semesters; and, the redesigning of courses at entry level to ease the students' transition to HE.

3.3 In the light of the changes taking place in HE and the emergence of the view of students as 'consumers' of the experiences it offers (McCulloch, 2009; Barnett, 2011) concerns have arisen about the quality of teaching and learning and the provision of student support. In 1997, Dearing (1997) charged the HE sector with the pursuit of 'excellence' in 'teaching and learning' (p.7). As a result, for over two decades curriculum change has been driven by key organisational agents and by the funding of development programmes including: Higher Education Quality Council (HEQC); Department for Education and Employability (DfEE) (then: Department for Education and Skills – DfES; Department for Innovation, Universities and Skills - DIUS; now Department for Business, Innovation and Skills - BIS), Quality Assurance Agency for Higher Education (QAA), Higher Education Staff Development Agency (HESDA), National Coordination Team (NCT), Learning and Teaching Support Network (LTSN), Institute of Learning and Teaching and (ILT) (later the Higher Education Academy - HEA), Centre for Excellence in Teaching and Learning (CETL), National Teaching Fellowship Scheme (NTFS), Economic and Social Research Council (ESRC) with its Teaching and Learning Research Programme (TRLP), Fund for the Development of Teaching and Learning (FDTL) and the Teaching Quality Enhancement Fund (TQEF). The HEFCE-funded National HE STEM Programme should be seen as part of this wider movement for change. The response of the HE system to these initiatives has included: a shift to learning outcomes models; the stipulation of aims and objectives in module and programme specifications; an increase in subject benchmarking; assessment becoming increasingly complex and seen as a key driver for learning; and, a greater emphasis on staff development. As a result curricula are now designed: as a series of modules with the provision of detailed specifications setting out the intended learning outcomes; with an increased focus on the connection between aims and objectives and the methods of assessment; and, to show how module level learning is connected to the overall learning offered by a degree programme.

3.4 Integral to the changes outlines above are the opportunities that have been created to professionalise teaching in HE - to challenge the assumption that whilst university staff may be specialists in their subjects they are not necessarily experts in the practice of education. These opportunities have been provided by means of: the QAA Subject Assessment; the TQEF; and, the NTFS. Their efforts have been supplemented by funding council strategies, and the activities of the ILT, the HEA, and the Subject Centres and CETLs. In addition the ESRC has supported pedagogic research in HE. The sector has responded to this challenge through: QAA sponsored peer reviews to examine curriculum designs; the provision of expertise to support the curriculum review-design process; training and development for teaching staff; and, accreditation through the professional bodies. This has been accompanied by: systematic gathering of student feedback; the use of evaluation data to improve teaching and learning; and, improved curriculum design based upon educational concepts and principles informed by educational research.

3.5 Bauman (2000) highlighted the need to develop the capabilities and personal qualities required for living in a 'liquid age' especially with regard to the economic imperative for a highly skilled workforce that can adapt to rapid and continuous change. Clearly, the HE sector has an important role to play in helping students to develop those capabilities and attributes. This has resulted in a developmental agenda driven by government agencies (e.g. DfEE and QAA) in collaboration with employers and their associations, and with the support of student. The HE system has responded to this challenge by seeking to enhance the students' employability through: the involvement of employers in curriculum design and review processes; negotiated work-based learning relevant to the students' programmes of study; the introduction of Foundation Degrees and Competency Based Degrees; and, increased opportunities for people in employment to learn in the workplace.

3.6 The 'market' subjects HE to the needs and aspirations of society and this notion has been incorporated into government policies administered through the funding councils along with the introduction of student tuition fees to finance undergraduate courses. Following the Browne Report (2010), the subsequent White Paper 'Students at the Heart of the System' (2011) heralded the government's plans to raise fees for the 2012-2013 student intake. The expectation is therefore, that future entrants to HE will not only be seeking a university education, but value for money as well (see Foskett et. al., 2006; Barnett, 2011). This has led to a growing view, reflected in government policy, that students are becoming, 'choosier and more demanding consumers of the higher education experience' (Mandelson, 2009). The overall effect of this has been to move learning in HE in the direction of greater accountability and responsiveness to student choices and expressions of their satisfaction (or otherwise). The HE sector has responded to these 'market forces' in a number of ways including: the promotion of institutions and their courses both at home and overseas; the development of operations such as campuses in other countries; an increase in the number of vocational courses; the development of strategies for widening participation and access; the creation of flexible modularized curricula that give students greater choice; involving students in the formal structures and processes of institutions; and, a concern for the quality of the 'student experience'. With regard to the curriculum the following changes can be also discerned: an increased emphasis on employability; the growth of new degree programmes that address niche markets with regard to employment; the abandonment of courses that fail to attract students; new partnerships with employers and other providers; customised support for students to meet their individual needs.

3.7 HE has also been subject to pressures for change that have their origins in the view that high value should be placed on learning for reasons other than the economic i.e. that learning has a positive impact on the development of the whole person, and is of benefit to the wider society in terms of the contribution of education to citizenship and commitment to civic responsibilities. This is a view that has been supported by the successive governments (Dearing, 1997, Fryer, 1997 and, Kennedy, 1997) and its influence can be detected in HE in: the increased opportunities for off-campus learning; policies that encourage systematic personal development planning; and, the promotion of extra-curricular activities to support personal growth and an appreciation of the idea of citizenship and social responsibility. This has been accompanied by changes to the curriculum including the development of: strategies to improve student autonomy and develop the capacity to learn in different contexts; the design of curricula that foster reflective learning; a greater emphasis on personal development planning; and, the recognition and accreditation of prior experiential learning.

3.8 Whilst there has been increased investment in HE, the funding for each student (unit resources) has decreased significantly in order to finance expansion in student numbers. HEIs have responded to the funding council policies of successive governments that have driven these developments by introducing what they regard as cost effective and 'more efficient' methods for the delivery of teaching and learning that include: organising the curriculum so that more students to be taught without increasing staff contact time; reducing class contact time; and, introducing teaching methods that favour student independence and autonomy. The impact on the curriculum resulted in: reductions in costly experiential learning such as fieldwork; and, the replacement of experiments that required expensive equipment by computer-based simulations. This pressure for change is constantly developing and can be linked with the use communications and information technology (C&IT) to facilitate student learning. This not only driven by the view that this will enable the costs of education to be reduced, but that it will facilitate the widening of access to HE and create opportunities for innovation in teaching and learning. It has been supported by large-scale investment through DfEE/DfES, DTI, Funding Councils, JISC, LTSN, UFI and e-university. In turn this has put pressure on HE staff to make use of new technologies - not only to provide students with opportunities to develop their C&IT skills but to deliver teaching and learning more cost effectively. It is not surprising therefore, that HE has witnessed: a large investment in C&IT at system and institutional levels; funded C&IT initiatives (e.g. by TLTP, CIT, FDTL); a national JISC committee structure for driving and funding infrastructure development; and, the creation of new Internet based organisations (Ufi and E-university). The resultant changes to the curriculum have included: the development of virtual learning environments (VLE) to support teaching and learning; creation of opportunities to learn through the integration of VLEs into the design of the curriculum; increased opportunities for C&IT-based learning within the curriculum; and, the adoption of curriculum management tools (e.g. to enable students to manage their own learning).

3.9 The external forces for change to which the HE sector has been subjected have been accompanied by those which are self-determined from within including the commitment of academic staff to enhancing the curriculum by improving their professional practice with regard to the design and delivery of teaching and learning. In summary, over recent decades the HE sector has been faced with various challenges that have resulted in a period of rapid change. The key forces for change have been largely external, including 'top-down' pressures, as a result of government interventions and market forces. The resultant changes have been extensive, across the sector and within individual HEI - the National HE STEM Programme should be seen in this wider context.

Overview of the National HE STEM Programme

3.10 STEM refers to the fields of study or disciplines located within science, technology, engineering and mathematics. The National HE STEM Programme has been funded to further a set of development activities by HEFCE and HEFCW, across widening participation and higher-level skills themes. The broad aims of the programme are to:

- Sustain the current efforts aimed at increasing demand for Strategically Important and Vulnerable Subjects (SIVS) i.e. Chemistry, Mathematics, Physics and Engineering within Higher Education (HE) through targeted interventions that were HE-specific and built upon previous development activity.
- Address the requirements of employers for economically valuable skills by ensuring that those delivered by the STEM disciplines in HE are aligned more fully with those needs.
- Support the development of more flexible, responsive and accessible provision in the STEM disciplines that is designed to facilitate re-engagement in HE study by members of the existing workforce.

3.11 Between 2005 and 2010 HEFCE funded four pilot projects (see below), each of which was led by a professional organisation: 'Chemistry for Our Future' (RSC); 'Stimulating Physics' (IOP); 'The London Engineering Project' (RAE); and, 'more maths grads' (MSOR on behalf of the Mathematical Societies). These projects initiated discipline-based activities designed to increase demand for, and to widen participation within, the STEM disciplines in HE. Three of these pilot projects ended in July 2009 – with the fourth 'more maths grads' being completed in January 2010. However, in policy terms discipline specific activity to widen participation has continued to be a priority area. The strategic aim of the National HE STEM Programme is to build upon the outcomes of the four pilot projects, and take their work forward in an integrated manner in order to create sustainable provision across the whole HE sector in England and Wales.

3.12 The Programme has undertaken additional widening participation activities across the STEM disciplines, but their limits were carefully defined to avoid duplicating the work of other agencies. To that end the Programme has adopted an approach designed to ensure that HEIs are at the core of all its activities. It has been widely recognised since the Leitch Review of Skills (2006) that a sustained and coordinated effort is needed to ensure that

HE STEM programmes deliver graduates with an 'economically-valuable' skill set, and that skill levels in the existing workforce are raised. The HE STEM Programme therefore, has worked with HEIs, employers, and professional organisations to: facilitate the development of *'relevant, flexible and responsive'* provision, designed to up-skill the existing workforce; increase the exposure of HE STEM undergraduate students to the workplace; and, enhance the alignment between the skills developed by HE STEM curricula, and the skills required by employers of STEM graduates.

3.13 The National HE STEM Programme commenced on the 1 August 2009 and was completed on the 31 July 2012. However, it should be recognised that the scale of the challenge it faced was such that it was unlikely that a three-year programme of activity would be sufficient in itself to address all the issues - not least because capacity building across the whole HE sector is a longer-term undertaking. However, because the focus of the Programme has been upon the transfer and embedding of practice, rather than with its direct delivery, it is anticipated that many of the activities it has initiated will be will prove to be sustainable.

HEFCE funded HE STEM pilot projects (2005-10)

3.14 This 'Chemistry for our future' project was initially funded by HEFCE from September 2006 to August 2008 with the aim of helping to ensure that there is a sustainable base of chemical science within HE, which will attract able students from all backgrounds and provide chemical science courses appropriate for students and employers in the 21st Century. It received further funding from HEFCE to run for an additional year and the project officially ended on 31 July 2009. Aspects of the 'Chemistry for our future' programme have been continued as part of the RSC's contribution to the National HE STEM Programme (e.g. the 'Context and Problem Based Learning' and, 'School Teacher Fellows' projects).

3.15 The IOP and the Science Learning Centres formed a partnership to run the 'Stimulating Physics Network' in order to support physics teachers and their pupils in England. The aims of this network are to improve the pupils' experience of physics and to reinvigorate the culture of the subject in the whole school. The network consisted of 37 Physics Network Coordinators and 23 Teaching and Learning Coaches – all knowledgeable, experienced and enthusiastic specialists who were supported by the Education Department of the IOP. The main goals of the Stimulating Physics Network are to: improve student perceptions of physics; increase participation in physics at A-level; increase the proportion of girls choosing physics A-level; develop a better appreciation of physics careers and careers where a physics qualification is an advantage; improve the quality of physics lessons, making them more effective, engaging and enjoyable; increase the amount of physics-based enrichment and enhancement activities in schools; and, improve the engagement of school senior leadership teams and increase the value given to physics and subject-based continuing professional development.

3.16 The RAE led the 'The London Engineering Project' in partnership with schools, colleges, universities, science and engineering education charities, and industry. The aim was to facilitate an increase in the number of individuals with engineering skills in London by developing the progression routes would take students from school, through FE and HE and on into the profession. To that end it has attempted to widen participation by engaging with women and with Caribbean, Bangladeshi and Pakistani students - all of whom are under-represented in engineering. This has been done through outreach activities in schools and the provision of attractive, relevant engineering courses in local universities populated with students from London schools and FE colleges. Employers have played a significant role in these development activities by helping to create new university courses, and to promote the advantages of working in engineering to students in schools and colleges.

3.17 'More maths grads' was a three-year project (2007-2010) funded by HEFCE to develop, trial and evaluate means of increasing the number of students studying mathematics, and encouraging participation from groups of learners who traditionally have not been well represented in HE. The project was administered from the University of Birmingham and regional officers worked in each of the three pilot areas: East London; West Midlands; and, Yorkshire and the Humber.

Fund for the Development of Teaching and Learning (FDTL)

3.18 A Fund for the Development of Teaching and Learning (FDTL) was established in 1995 with the intention of stimulating the development and dissemination of good teaching and learning practice across the HE sector. Bids for FDTL funding were invited from HEIs that had demonstrated high quality in their educational provision, as judged by the teaching quality assessment (TQA) exercise. Between 1995 and early 2009, FDTL supported 164 projects across the HE sector.

Teaching Quality Enhancement Fund (TQEF)

3.19 Through an investment of over £180 million over the period 1999-2000 to 2004-05, TQEF supported three strands of developmental work aimed at the enhancement of learning and teaching in HE: institutions; academic subjects/disciplines; and, individuals. The institutional strand centred on funding HEIs to support curriculum enhancement, and the production and implementation of institutional learning and teaching strategies. It was a requirement that institutional plans for these developments had to be approved by the funding council, and the actions taken had to be reported in an annual monitoring statement. It was initially suggested that TQEF funding for HEIs should be based on competitive bidding, but after a consultation process the funds were provided on a formula/entitlement basis.

3.20 The second strand (academic subjects) included: the network of 24 Subject Centres and a Generic Centre initially established under the LTSN initiative and subsequently part of the HEA; the FDTL and the last phase of the TLTP. Finally, the individual strand consisted of the NTFS, and was contracted initially to the ILT and subsequently to the HEA. The TQEF was created in 1998 after the recommendations of the Dearing Committee that led to the creation of the ILT. The proposals of the Dearing Report (1997) as subsequently implemented by the funding bodies were intended to raise the status of learning and teaching in HE, and this became a key element in HEFCE's own strategy for the advancement of learning and teaching.

The role of brokerage in long-term change and institutional impact in HE

3.21 This section introduces ideas drawn from the literature that has helped to inform the research from a theoretical perspective. A concept that has been recurrently found to be useful is that of 'brokerage'. This refers to processes that facilitate change at all levels in HE thereby enabling it to be more responsive to society and more competitive. The concept of brokerage is complex and challenging (Jackson, 2003) yet, it is also inherently 'multi-layered' because it is *'epistemological and practical, performative and ideational and ontological and communicative all at once'* (Barnett, 2003; xix). It is this quality, including its association with key notions, that together were viewed to act as an appropriate heuristic to cast light upon the main focus of this investigation - long-term curriculum change and institutional impact within HE.

3.22 Brokerage is an important and necessary feature of the complex, adaptive HE systems that currently exist in what has been called a 'liquid age' (Bauman, 2000). Educational organizations are brokers of change and many of those who work in universities[2] engage in brokerage - though they may not view it as such let alone describe what they do in those terms. Nevertheless, it has been argued that the process of brokerage is an essential vehicle for the promotion of change in HE (Jackson, 2003). It may be helpful in this context therefore, to define the term and outline key ideas that are related to it[3]. According to Jackson (ibid.) brokerage is: *'an intentional and purposeful act in which the broker seeks to work in collaborative and creative ways with people, communities, networks, organizations, ideas, knowledge and resources to develop something new or change something' (p.5). He went on to say that brokerage is a 'creative belief-led process: a personal art rather than a disciplinary science'* (p.80).

3.23 It is argued in the literature (notably by Jackson) that effective brokerage in HE involves a number of processes and actions that include:

- Envisioning and anticipating change i.e. the person acting as a broker must be: aware of the need for change; capable of defining and articulating problems and imagining solutions; able to persuade others to take on change by providing a clear rationale for what needs to be done.
- Creating the conditions that enable change to occur i.e. among other things the broker must: identify and define realistic, worthwhile and achievable goals; demonstrate a personal commitment to the changes that are proposed; establish and maintain personal credibility; and, enable others to collaborate, develop a sense of ownership and further their own development.
- Engaging people and organizations in debate in order to: improve understanding; shape the nature of the proposed changes; and, facilitate innovation. In other words the broker needs to become a *'multi-skilled anthropologist'* who can *'go inside and comprehend not only the needs and desires, but the language, politics, positioning and outlook of different parties'* (Barnett, 2003 p.xvii).
- Creating the structures and processes that facilitate change including: the policy framework; regulatory guidance; physical resources;

2 This includes for example, a Faculty, College or Department.

3 The outline is an adaptation of Jackson (2003) p.19-27.

administrative support; communication networks; and, opportunities to improve practice.

- Facilitating the production, diffusion and use of knowledge for the purposes of change through dialogue that encompasses the know-how (or tacit knowledge) embedded in the practices within working communities.

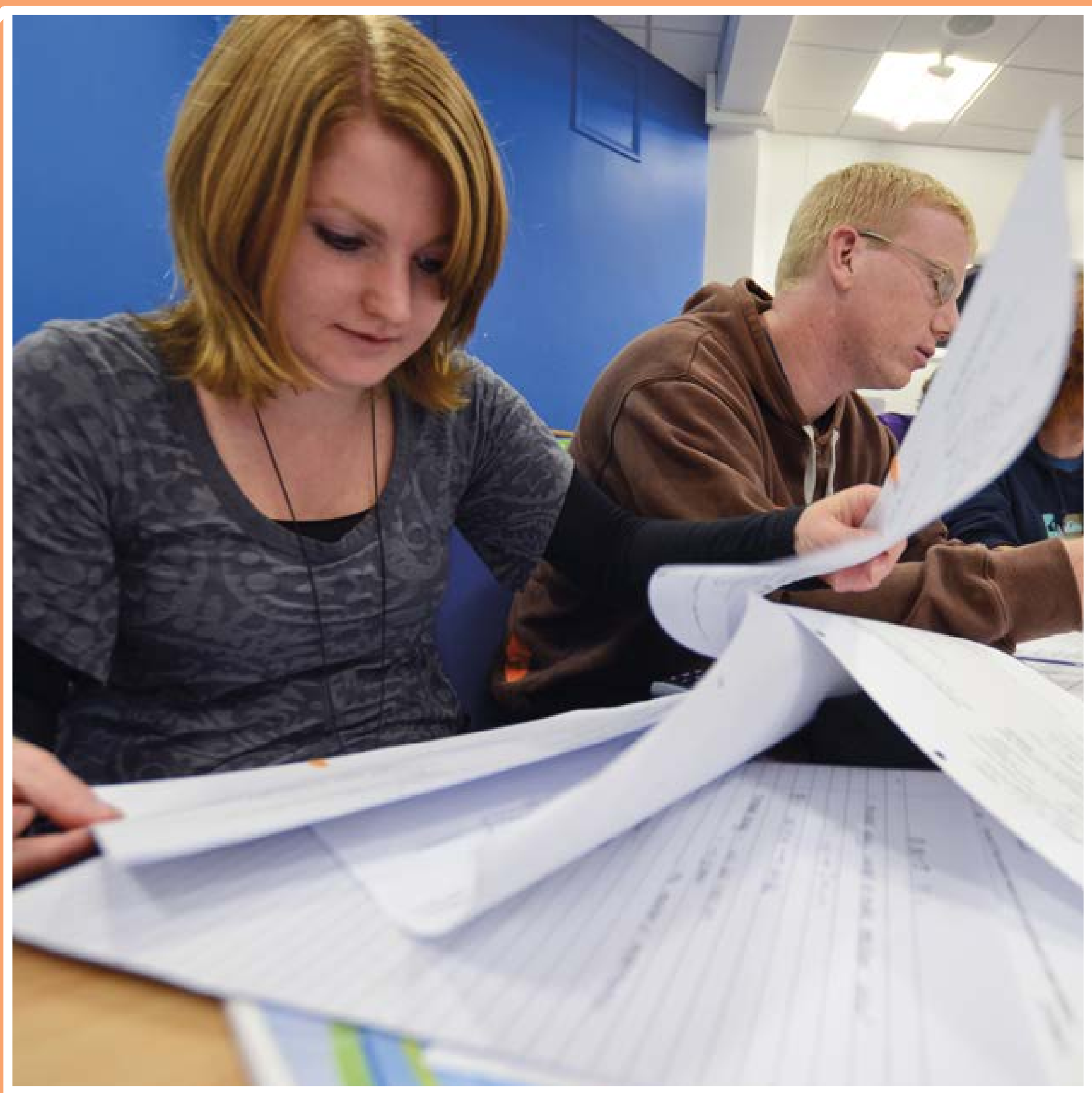
3.24 Brokerage therefore, involves engagement within particular 'communities of practice' (Wenger, 1998), which represent the social structure for the ownership and creation of knowledge. Because they accumulate collective learning and embed it in social practices communities of practice are major repositories of knowledge and expertise - the key resource for the knowledge broker. Within these communities the knowledge broker plays a key role in the production, diffusion of information and ideas for change including the use of knowledge held by different practitioners. Although academic communities are noted for their 'tribal' and 'territorial' tendencies (Becher and Trawler, 2001), the diffusion of brokered knowledge can extend beyond an academic territory, to an institutional level and even into other HEIs. Change at this scale however, requires the development of a networked community of brokers acting as 'change agents'. The establishment of information delivery systems such as email, the web, conferences, workshops and other events have all helped to further systemic brokerage which is dependent on the effectively dissemination of knowledge. If the HE system therefore, is to successfully broker knowledge for change and achieve the maximum benefits it must become: *'masters for change - [that involves] the people and organizations adept at the art of anticipating the need for, and of leading productive change'* (Jackson, 2003:32).

3.25 It is also argued that behaving honestly and ethically is key to the success of effective brokerage. People who care about HE will only participate in a brokerage process if they feel secure in the fact that they are not being manipulated, forced, or sense that there is a 'hidden agenda'. Consequently, the brokerage objective needs to be clear and transparent, and it is essential that brokers communicate openly with people, communities and networks in order to maintain the integrity of their projects. There is an onus therefore, upon brokers to demonstrate that they are behaving honestly and with integrity in order for people to feel valued and believe in the process for themselves.

3.26 The processes outlined above provide insights into the art of brokerage. Brokers act as 'change agents' in HE within different contexts and at various levels, and this can involve individuals, communities or extend to wider organizational systemic brokerage. For the various process of brokerage to be successful and long-term change and positive impact to take place, the broker needs to possess various qualities and characteristics. For example, the role of a broker in HE will require: a sense of belief and purpose; the capability to be visionary and identify where change needs to take place and how; the ability to be creative and imaginative; the capability to act; the ability to create supportive and facilitative structures, including communities and networks; the ability to work within and between different communities of practice in a credible and authoritative manner; the capacity to be strategically and politically connected; the ability to learn, reflect and help others to learn from the experience of doing; the capability to represent interests and sell success; and the capacity to be proactive and opportunistic. Therefore, as suggested earlier, the art of brokerage is complex and multi-layered.

3.27 In terms of wider institutional change it has been highlighted that this requires a systemic network of brokerage for it to be successful. In many ways, this organizational brokerage connects to Barnett's (2011) argument that UK HEIs need to change and develop so that each one becomes an 'ecological university'. Building upon his ideas of the university, Barnett (ibid.) views an ecological university as best suited to the unfolding demands of the future. The term ecology indicates *'systems of relationships between organisms and their environment'* (p5). Accordingly, the modern university lies amid multiple networks and the ecological university takes responsibility for the total environment. This ecological domain includes personal, social, cultural, institutional, technological and knowledge environments. Thus, the notion of an ecological university proposes a care and concern towards its environment and subsequent interconnections with and responsibilities towards the wider world. Further, impact upon the environment is provocative, pointing more towards an ecological environment that is ethical, has a beneficial impact, is sustainable and ultimately, self-sustaining.

3.28 The 'Intellectual Capital model' developed by the Henley Management College (2002) also provided a useful framework for the examination of the data collected for the purposes of this research. The model draws on thinking on the concept of 'intellectual capital', especially the work of Edvinsson and Malone (1997) and Sullivan (2000). Its value in this context is that it takes a broad view of the intangible capabilities and assets of organisations such as HEIs as well as providing a terminology with which those can be critically examined. In outline the model identifies four different forms of 'capital': human; network; structural; and technological. The concept of 'capital' is useful in this context because it suggests that organisations such universities possess resources, which they can 'invest' in the expectation that like financial investments these will yield future benefits or 'returns'. If properly directed therefore, these 'investments' should enable HEIs to achieve its strategic aims and objectives. Whilst the human capital of an organisation encompasses the capabilities of the workforce at all levels it is common for it to be divided into: 'managerial capital'; and, 'employee capital'. The former highlights the importance of the attributes of those who lead and manage an organisation, whereas the latter recognises the significance of the underlying quality of its workforce. The idea of network capital is especially apt in this context because it focuses attention on the external relationships (of e.g. a university department or an HEI) and can be divided into: 'reputational capital'; and, 'relational capital. According to the model, the structural capital is made up of: 'organisational capital'; and, 'process capital'. The former consists of the structure, culture and routines of an organisation; whereas the latter is concerned with the ways of working (formal and informal) by which an organisation delivers its services and produces its outputs. Finally, according to the model an organisation has what is known as 'technological capital', which consists of 'intellectual property capital', and 'innovation capital' i.e. its current knowledge base and capacity to respond positively to change. Concepts and ideas such as these and those discussed earlier have helped to provide an overarching theoretical framework that has guided this investigation.



4. Phase 1: Large-Scale Curriculum Enhancement Projects

Introduction

4.1 The National HE STEM Programme designated twelve of its projects as 'Large Scale Curriculum and Innovation Enhancement Projects' - the intention being that they would seek to bring about changes in their host institutions not just a module level but within whole programmes of study and across departments. However, within the broad funding strategy of the Programme they were in fact intermediate between small-scale activities such as those aimed at practice transfer rather than large-scale curriculum innovation, and from the sector-wide development projects that evolved from the HEFCE-funded pilots (see paragraphs 3.14, 3.15, 3.16 and 3.17).

4.2 Ten of the projects were based in single institutions, whilst two of them ('Education for Professional Engineering Practice' and 'Improving Conceptual Understanding in Physics') involved partnerships between universities. The former were awarded approximately £30,000 per project by the National HE STEM Programme whereas the latter were given proportionately larger amounts. Fifteen universities drawn from different types of institution across the sector were represented in the twelve projects as were different STEM disciplines - 3 in Mathematics, 4 in Engineering, 2 in Physics and 2 in Chemistry, with one project attempting to cover the STEM subjects in general.

4.3 The aims of these projects were directed towards achieving deep-seated changes in the design and delivery of the curriculum that would transform professional practice and the experiences of students. Innovations of this kind are difficult to achieve in the short-term not least because they are likely to require the brokering of facilitating organizational change including the revision of programme specifications and accreditation arrangements along with the negotiation of new relationships with employers. This places those leading projects in a situation in which they are required to act as 'change agents', and in which they depend on the support of others not least from senior management, but also from other colleagues and students. This phase of the research was directed towards capturing evidence that would reflect the insights gained by the project leads (and in some cases their immediate colleagues) who were closely involved in the implementation of these so-called large scale curriculum enhancement projects.

Data collection, processing and analysis

4.4 It was determined in the planning of the research that the evidence in **Phase 1** would be collected by means interviews, and that wherever possible these would be face-to-face, and that where it was not the exchanges would be by telephone and email - in the event this was necessary in only three cases. One whole day meeting of project partner HEIs was attended by one of the research team in the role of participant observer. The twelve projects were divided equally between the three researchers, and the interviews were conducted using a common set of discussion topics (see **Appendix 1**) derived from the aims of the investigation and the key questions. In preparation for the interviews the researchers read the relevant documents that were available at the time including project proposals, interim reports[4], case studies and journal articles. This prior desk research meant that the interviewers were able to conduct the interactions from an informed position, and to put the generic questions they posed along with the responses to them into context. Interviews varied in duration but generally were in the order of 45-60 minutes. Notes were taken during the interviews and in majority of cases the interactions were recorded – but only after those who were being questioned had given their permission. The recordings were not transcribed but were used to check the accuracy of the interview notes and to identify comments and observations that might be cited in this report.

4.5 Once completed the notes were reviewed by the interviewer who had conducted the interview and key points were extracted and transposed to summary grids to facilitate subsequent in-case and inter-case analysis. The results were then discussed at a team meeting in order to share initial perceptions of the key themes that were beginning to be evident in the data. Following that meeting each of the team members re-examined their interview notes and related summary grids in order to highlight what they now regarded as

4 Final reports from projects were in preparation and unavailable at the time the interviews.

being of particular significance and to add any further comments and observations. The summary of key findings that follow have been derived from the close examination of those interview notes and grids through a complex process perhaps best described as one of 'thematic induction'.

Key findings

4.6 The support received from senior managers who understood the aims of projects and had the positional authority to facilitate change was identified by those questioned as being a key factor in their implementation. This was said to have been especially important when projects were seeking to: obtain additional funding; secure 'buy-in' from internal and external partners; implement planned changes within short time scales; expedite decision-making at times of pressure; and, provide inexperienced project leads with practical support particularly when dealing with unexpected problems (see paragraph 4.7). Senior management involvement in the implementation of projects was said to have fallen into three categories: direct participation as project leads or as members of the team; practical support and encouragement by individuals who were external to the management structures of projects (e.g. Heads or Deputy Heads of School and Directors of Undergraduate Studies); and, support from those operating at a university-wide level (e.g. PVC Teaching and Learning). The following statements made by two of those interviewed illustrate the nature and importance of senior manager engagement and support: *'The project team met every three weeks in the Head of Department's office usually with the HoD involved…… The project lead is also Chair of the university's Admissions' Committee. The PVC Education is on that committee, so he was able to arrange a meeting for the project officer with the PVC - the person who really mattered. The project lead demonstrated his commitment to the project by volunteering to do two weeks in the lab demonstrating.'* (Durham University); and, *'The project had 'buy in' from senior managers who were embedded into the fabric of Faculty teaching and therefore had the authority to implement changes envisaged by the project: The Deputy Principal for Teaching was very supportive and signed off the project bid. Two of the collaborative team were Deputy Heads and Directors of Undergraduate Studies for their departments…….. Although the Deputy Principal for Teaching moved on, the involvement of the other two senior managers meant that the project continued to enjoy senior management support.'* (Imperial College).

4.7 Working within the strict time scales determined by the funding arrangements, project teams needed to be able to act quickly in order to implement the changes they planned to make. In these circumstances the direct involvement of project leads and other team members who held senior management positions at School and Faculty level and were strategically connected within their institutions was said by a number of those questioned to have been of critical importance in their case. This can be illustrated by the following examples from what was said: *'This fundamental change is something we've been able to drive by actually having people who can force change through as part of the team.'* (Project lead, Durham University)[5]; and, *'Inputs from above have meant that things that needed to change didn't have to change slowly. It could just be decided upon and done, and that worked really well.'* (Project officer, Durham University). Across the projects studied therefore, the direct involvement of senior managers was seen as a key factor in the ability of projects to achieve their intended outcomes. At the outset all the project teams included senior managers, and in most instances this remained the case throughout the life of the projects. These managers appear to have been able to use their positional authority to facilitate change and to broker the involvement of other senior managers in their institutions. However, it was reported that in two cases the direct involvement in projects of senior management that had been anticipated at the planning stage had not been forthcoming. In one case this was a result of *'a resignation from post'* and in the other it was reported that it had *'simply not materialized'*. Unfortunately, in both cases this resulted in relatively inexperienced project leads being left to work without this critically important form of support.

4.8 The timing of a project proved to be a significant factor in some cases with regard to acquiring and retaining the support of senior managers who were not directly involved in their implementation. In the case of one project (Sheffield Hallam University - Engineering) the timing was said to have been opportune because every six years all Faculties are required to review their programmes of study - and the re-validation of those courses was scheduled to occur in 2012. For a project starting in 2010 this provided an ideal opportunity to pilot innovations in teaching and learning, with a view to embedding them in the curriculum as an integral part of the

5 As Director of Teaching, the Project Lead had the authority to implement changes during and beyond the project-funding period. Change has also been facilitated by the Head of Department who has been involved in the project from the outset and often attended project team meetings.

forthcoming programme accreditation process. In this instance the close alignment of the project's aims with the strategic goals of the School and Faculty at that time was clearly advantageous in terms of senior management endorsement and support. However, in one of the other projects (Middlesex University - Engineering) the timing was less fortunate with regard to wider decision-making by senior management. According to the project lead (himself a senior manger with university-wide responsibilities) everything was progressing according to plan until the university embarked on a number of large-scale innovations. Ironically, these changes were said to have been: *'highly supportive of the STEM agenda'*, but inadvertently they *'caused severe disruption to this project'*. The lead went on to say that *'in particular, the School structure was changed to create a new School of Science and Technology, widening the remit of the STEM provision considerable, and this required the small number of engineers within the existing School to take on massive extra developmental and planning loads'*. At the same time it was decided to: *'relocate engineering provision to the main campus into purpose-built accommodation, once again demonstrating its commitment to the STEM agenda.'* Unfortunately, these unforeseen institutional changes impacted *'severely on the capacity of the project team to complete the project'* as originally planned and within the agreed timescale.

4.9 The research showed that the designated leads had varying degrees of experience with regard to directing large-scale curriculum enhancement projects. All of them had already been involved in various forms of innovation at a departmental level including developing new modules and resources, and devising new approaches to the delivery of teaching, learning and assessment. However, for some it was their first experience of managing an externally funded curriculum development project. Consequently, they were faced with the task of maintaining an overview of their projects, keeping them on schedule, being accountable to their own institutions and to an external funding provider - despite having little experience in such a leadership role. Even those who had considerable prior experience of managing internally-funded projects discovered that the requirements of leading a project funded by the National HE STEM Programme presented new challenges in relation to: coping with the additional workload; meeting externally-imposed deadlines; coordinating activities with university colleagues (and in some cases partner HEIs); and, addressing funding requirements with regard to evaluation, dissemination and reporting. It is not surprising therefore, that for some it proved to be a steep learning curve as illustrated by the following example. *'He only had experience of managing internally funded projects in the university concerning research into peer support, e-assessment and online resources; this is his first externally funded project.'* The individual concerned described himself and others like him as *'cheerful amateurs'*, and expressed the feeling that with hindsight his project *'could have been run better'*. (University of Leicester - Mathematics)

4.10 Other project leads had substantial degrees of prior experience of managing externally funded projects – many having had leadership roles in several projects. For example, the lead of Loughborough University's project was able to build on experiences derived from directing a HEFCE-funded CETL and co-directing the **sigma** Network (see paragraphs 5.29-5.38). Similarly, the on-going involvement (since c1990) of the project lead at Sheffield Hallam University in curriculum innovation in the HE sector (including initiatives funded by FDTL, HEFCE and HEA) meant that *'as a result of successful prior experience the project has been efficiently led and managed'*. The same can also be said of the lead of the Physics project at the University of Leicester who was able to draw upon his experience of having previously directed the piCETL as well as having led other internally- and externally-funded curriculum development initiatives. Those with experience of this kind of directing or managing externally funded projects showed themselves to be capable of acting as 'change agents' i.e. to successfully broker innovation within their own institutions (and in others across the sector). The record of these individuals indicates that they possess a number of shared characteristics including: clarity of purpose; strong commitments to improving the quality of teaching and learning; capability with regard to making decisions and taking action; the ability to build and participate in 'communities of practice'; being strategically well-connected; and, having the capacity to learn (and helps others to learn) from experience. They are also been successful when it comes to disseminating ideas and promoting success (as evidenced e.g. by the workshops they have led, presentations given at conferences and their lists of scholarly publications) as well as being proactive when it comes to taking advantage of development opportunities that arise such as those offered by means of the National HE STEM Programme.

4.11 The projects were dependent to a substantial degree on the openness, and support of staff colleagues at various levels (School, Faculty, University) to the changes they were seeking to implement. However, this was not always immediately forthcoming – as one of those questioned put it *'another challenge has been that some staff are suspicious of the new methods and they require more persuasion'* (University of Leicester – Mathematics). Where this proved to be problematic, planned changes were subject to delays and/or had to be amended. The reasons offered by those questioned for staff resistance, and in some cases to the subsequent scaling down of a project's intended outcomes included: slowness on the part of colleagues to recognize the merits of the proposed changes; and, an unwillingness to become directly involved until they had seen for themselves that the proposed methods of teaching and learning would work successfully in contexts with which they were familiar[6]. It was not surprising therefore, that problems occurred as a result of colleagues giving priority to other courses and activities including research. One of those interviewed expressed this as follows: *'The project has been hindered by the commitments to other courses by a staff member, resulting in greater time constraints'*. The project lead went on to say that at the outset he *'thought that staff would be involved with various parts of the planning- implementation process'*, but some staff members' showed resistance to *'implementing the new teaching methods'*. The lead noted that he had tried to overcome this by engaging colleagues in training courses on problem based learning, but found that some of them still *'wanted to see the new methods working well before committing to their involvement'* (Project Lead, University of Portsmouth).

4.12 The consensus amongst those questioned was that in order to counteract difficulties such as those identified above, it was essential for them to ensure that other members of staff were: clear about the benefits of the proposed changes to the curriculum; kept fully-informed of developments; given opportunities to suggest ideas and voice opinions; able to engage in a dialogue about potential problems and how they can be overcome; confident that their concerns and perspectives were being taken into account throughout all stages of projects; and, involved (where appropriate) in planning and implementation. In several cases relatively few members of staff were directly affected by the projects. Nevertheless, it was judged to be important that the staff as a whole remained broadly supportive of projects otherwise there was a danger that they would be operating in a negative climate, eventually becoming marginalized within their Schools and Faculties thus limiting their potential for practice transfer and longer-term impact. In some cases the commitment of non-academic staff was also essential with one project involving new approaches to lab work taking great care to include them in the planning process: *'The technical staff were involved from the outset in all the staff meetings (which included the Head of Department, project lead and project officer) about the project and they had their own voice and were able to feed ideas into the process and to highlight potential problems (e.g. logistical issues) that needed to be addressed. The technical staff appreciated this and were very flexible and willing to do things at short notice'*. In addition the learning technologies team at IT services was drawn into the planning process resulting in *'quite a lot of input – though this required another layer of liaison and negotiation that needed to happen. Part of the success of the pre-labs has been that they sourced and got good resources to run on the VLE for students. We had to say to the learning technologies team at the IT service that we have a big new package coming in and it has to work across the whole of university network and by a date in the near future. The success of the pre-labs depended on their ability to do this.'* (Project Officer, Durham University).

4.13 Despite their commitment to enhancing the curriculum, some projects experienced problems in getting their students to respond positively to the innovation they proposed to introduce. In one case the project lead expressed the opinion that this was due to students being *'risk averse'* as a result of the *'economic uncertainties'* at a time of austerity, as well as to a lack of available incentives for students to adopt the changes the project was seeking to pilot. He expressed this as follows: *'The course has yet to be piloted. Significant attempts have been made, eventually leading to strong 'buy-in' from several companies both big and small, but it is proving difficult to persuade students to be first to take the 'hybrid degree course' option. In addition student numbers in STEM subjects at Lancaster are currently very buoyant indeed – so that recruitment 'incentives' in the form of new degree programmes offering industry based modules are not really necessary. ….. 'With hindsight some 'pump priming' funding*[7] *would have helped to launch the new programme'* (Project Lead, Lancaster University).

4.14 Other projects sought to secure the commitment of students by inviting them to become active

6 Such a response to a proposed change to the curriculum has been referred to as 'pragmatic scepticism' Doyle & Ponder (1977).

7 Had it been available such funding would have been used to offer some form of inducement to students to participate in the pilot.

participants in the development process – to be collaborative partners in a joint enterprise rather than passive consumers of changes planned for them and delivered to them by others. This was accomplished in a variety of ways including student representation on planning committees and working groups and, through the provision of feedback by students on the new approaches to the design and delivery of the curriculum. In one case (- Loughborough University) an internship scheme enabled academics and students to work together over the summer vacation in order to: analyse a pair of Year 1 modules that students had previously found to be troublesome; re-design those modules; and, develop new teaching resources. Following training provided by the Teaching Centre the students then went on support the delivery of the revised modules by acting as mentors. The adoption of this approach was fully endorsed by the National Union of Students (NUS) and was aligned to institutional policy at the university with regard to student engagement[8]. It was said to have brought the following benefits: it ensured that the student perspective was incorporated into the change process from the outset; it increased student involvement in, and commitment to, the revised curriculum; and, it impacted positively on the students' experience and achievement.

4.15 According to a number of those questioned, the National HE STEM Programme's funding period (2010-12) allowed insufficient time for the systematic planning, implementation and evaluation of large-scale curriculum change – especially when this was linked to external as well as internal accountability. In at least one case it was envisaged that in order to achieve its objectives the development process initiated by the project would have to extend well beyond the two-year time limit. The general view of the stakeholders questioned was that more time was needed – especially for the initial planning stage – for large-scale curriculum enhancement projects such as those considered here. The problems can be illustrated by reference to the views expressed by two of those interviewed: *'To do large scale curriculum innovation and properly evaluate it and properly plan it, have it all completed and be confident that you've got the right thing before you launch it 18 months was never going to be long enough.'* (Project Officer, Durham University); and, *'The procedural constraints associated with compiling and publishing a course prospectus and negotiating accreditation are a longer-term undertaking that is beyond the scope of a short-term intervention. Although circumstances have prevented the piloting of modules from that would make up the new hybrid degree courses, the groundwork has been done for their implementation including: the design/validation of the new course(s); the appointment of new academic staff; and, reaching agreement with a significant number of industrial partners.'* (Project Lead, Lancaster University)

4.16 Project leads were not only required to work within these time constraints, but to draw upon their own leadership and management skills in order to address a range of challenges, many of which could not have been foreseen, including bringing the change process into line with the planned schedule for the accreditation of programmes by the professional bodies (an administrative problem that had to be skillfully managed). Time pressures were also exacerbated by the fact that in several cases academic staff had very little time available, and experienced problems when trying to balance the conflicting demands of their on-going research and teaching commitments with implementing their new projects. One of those interviewed expressed this as follows: *'it has been hard as a busy academic to keep up and overall the project has not been run as he would have liked because of other concerns and commitments, which have taken time away. If offered the same conditions to undertake a research grant he wouldn't have bothered.'* (University of Leicester, Mathematics). Problems also arose when the work commitments of members of the project team were unexpectedly changed during the lifetime of a project e.g. *'A staff member who was expected to work on the new degree programme has become involved with other commitments on other courses and has not contributed as much as expected. This resulted in additional demands/ time constraints on the project lead. One result of this is that publishable resources will not be available by the end of the project. However, there is a sense that the initial hard work will be worth it in the end, with a course that will almost 'run itself''*. (Project Lead, University of Portsmouth)

4.17 The problems such as those identified above were resolved in three cases (Durham University, Imperial College and Sheffield Hallam University - Engineering) by the appointment of project officers (or managers). In all three instances the project leads took pressure off themselves by making these appointments – and by recruiting individuals with whom they had worked previously in one capacity or another. Hence the appointees were not only 'known quantities' but were already familiar with the contexts in which they would be working. Having a dedicated project officer or manager to

8 See paragraph 6.11 for a fuller discussion of student engagement at Loughborough University.

work under the direction of the project lead in this way brought a number of advantages as revealed by one of those interviewed: *'The project officer has been responsible for running the project on a day-to-day basis with support from the me the project lead……….having someone dedicated to developing and getting the course up and running was very important. The alternative would have involved other members of staff having to fit this around their other teaching, administration and research commitments. Having one person to keep consistency whilst liaising with people was a key success factor'* (Project Lead, Durham University). Another strategy for reducing the demands on project leads was the appointment of evaluators. This not only freed project leads of an important area of responsibility, but also introduced an independent perspective to the collective thinking in the form of external feedback – someone to act as a 'critical friend' to the project team. The project at Loughborough University and the Engineering project at Sheffield Hallam University (working in partnership with Loughborough University and London South Bank University) were two projects to have benefited from the formative feedback provided by such an arrangement.

4.18 Two of the projects involved institutional partnerships from the outset whereas others were developed them during the funding period. In the case of one of the former (Sheffield Hallam University, London South Bank University and Loughborough University) observation at a project meeting demonstrated how effectively the partners were able to function together within a 'community of practice'. The success of their collaboration rested on working within a common framework for the management of the whole project in the form of mutually agreed strategic and operational plans. The latter set out clearly what actions would be taken, when they were scheduled to occur, how they would be implemented and finally by whom. This enabled development activities across the partner institutions to be co-ordinated, and in turn this facilitated the systematic discussion of issues and sharing of experiences at project meetings. The presence of the evaluators at these meetings provided valuable inputs from an external perspective - not just about the technicalities of evaluation but in relation to other aspects of project implementation. However, difficulties were reported to have occurred in other projects involving collaboration between partner institutions. The problems they encountered stemmed from a number of factors as follows: the different scales of activity and rates of progress achieved in different institutions e.g. *'Hull has developed resources and trialed them, whereas at Leicester the resources are still under development and have only received feedback from a small sub-set who have trialed them. Hertfordshire have developed and trialed resources but on a very small scale. Durham has also developed and trialed and is at the stage of accessing the developed resources.'* (University of Leicester, Physics); differences in the levels of positional authority among the project leads e.g. *'The project leads in two of the partner universities have the ability to get things done. However the project lead in the other HEI involved in the project is lower in the organization and therefore does not have the power to instigate change as easily.'* (University of Leicester, Mathematics); and, partners deciding to withdraw from the project e.g. *'Difficulties with planning and implementation have been caused by a lack of involvement by other HEIs and also some HEIs dropping out of the project.'* (Sheffield Hallam University, Mathematics).

4.19 In the opinion of those questioned for the purposes of this research it was still early to attempt to evaluate the full impact of the large scale curriculum enhancement projects within their own institutions let alone on the wider HE sector – as one of those questioned suggested *'the best is yet to come'*. This can be illustrated by reference to the 'Education for professional engineering practice' at one of the project partners (Loughborough University). In this instance, small group projects based on multidisciplinary topics have already been introduced into the curriculum to students in Year 2. However, the intention is that the learning experiences they have acquired will then be built upon in Year 3 through mixed discipline groups who will be invited to solve authentic problems derived from industry. Then, when they reach Year 4 the students will not only undertake individual project work, but will also be asked to act as mentors to students starting the learning process in Year 2. It could be several years therefore, before the impact of the projects can be assessed especially in relation to those that encountered unforeseen difficulties and were forced to put on hold some of the changes they had planned to implement. However, it is evident that many of the projects have been catalysts for deep-seated changes in their Schools and Faculties and that the curriculum innovations they have initiated are transferable both within host institutions and across the sector. There was also broad agreement amongst those questioned that their projects had achieved a wide range of positive outcomes many of which underpinned the changes to the curriculum that were aimed at improving the students' transitional experiences, retention, achievement and employability. These include: the stimulation of critical reflection about teaching and learning by both staff and students (e.g. through the use of on-line blogs); an enhanced understanding of student learning needs; new ways of engaging with students; increased use of student as mentors; improved feedback to learners; opportunities for staff development through participation in planning and managing innovation; wikis that offers ideas and practical advice; improved team working in relation to the design and delivery of teaching and learning; and, the development and consolidation of practitioner networks (or 'communities of practice') within institutions and across the HE sector. This wider impact was summed up by one of those interviewed as follows: *'The School has witnessed a culture shift in the way students are involved in their courses made possible by the 'buy-in' from five mathematicians and five maths educators (including senior staff who have been directly involved). The latter are in a strong position to influence the Teaching and Learning Strategy for the whole School and thereby continue to deliver sustainable improvement'* (Project Lead, Loughborough University).

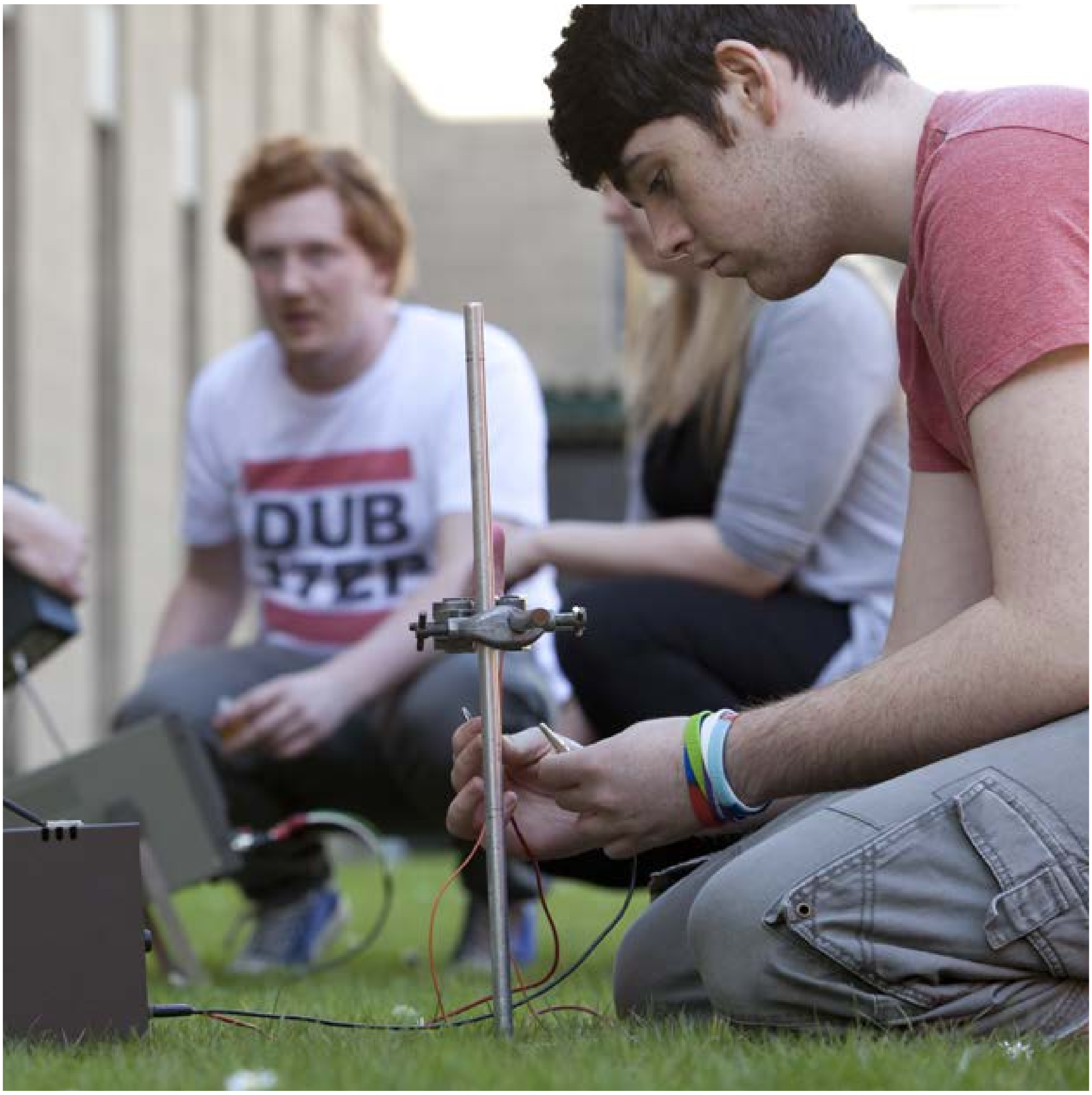
4.20 The responses of those interviewed to questions about the sustainability of the innovations for which they had been responsible were generally optimistic - despite acknowledging that the HE sector is faced with an economically uncertain future. A number of arguments were advanced to support the view that the changes they had been initiated would be self-sustaining i.e. would not require a further input of funding comparable to that already received from the National HE STEM Programme. The main reason offered by those questioned for this was that the greatest expense had already been incurred by the projects i.e. in meeting such initial development costs as employing project officers and external evaluators. They went on to say that where changes have been embedded into programmes of study they can be sustained out of School and Faculty teaching and learning funds. The on-going support of senior management, staff and student for innovations introduced by the projects was also identified as a factor that will also help to ensure their sustainability. At Loughborough University where such support has been forthcoming, funds have already been made available for the continuation in 2012-13 of student internships and peer mentoring as developed by the project. In the case of one project (Sheffield Hallam University – Mathematics) sustainability had been underpinned by the development of wikis to 'bank' evidence of the lessons that had been learned, and facilitate the on-going use and development of resources. In addition, those projects enjoying the support of professional organisations such as the RSC and the IOP expect the teaching and learning resources they have developed to be made available to other practitioners via the websites of those bodies. However, it was recognised that in future it may well be difficult to sustain certain activities in the absence of external funding. These include participation in professional networks or 'communities of practice' including attendance at workshops and conferences that incur travel and other expenses thus limiting the CPD opportunities open to staff and inhibiting practice transfer. Similarly, there was concern that financial constraints will also impose limits not only on the funding of curriculum enhancement initiatives, but also on pedagogic research. Such research provided the intellectual capital on which a number of the large-scale curriculum enhancement project were based, most noticeably in the case of the project at Loughborough University. Similarly, projects benefited from being able if they so wished to employ project officers or managers, and in some cases external evaluators – and none of those questioned expected that level of input to be sustainable. In the case of these projects, the National HE STEM Programme was able to build on over two decades of investment in teaching quality enhancement funding of various kinds and the consensus was that forward momentum that this has generated across the sector would be difficult to sustain.

4.21 In conclusion the following factors have contributed in varying degrees to the successes achieved by the large-scale curriculum enhancement projects that have been noted above.

- Projects benefited from having strong alignment of their intended outcomes with the strategic goals of their Schools, Faculties and the policies and development priorities of their institutions.
- Endorsement and support from senior managers with the positional authority to facilitate change was identified as being a significant factor in the successful implementation especially when they acted as project leads or as members of the project team.
- The timing of projects was an important factor in acquiring and retaining the support of senior managers. In the case of some projects this was opportune because their aims were closely aligned with the strategic priorities of their departments at the time, whereas in others instances their progress was disrupted as a result of high-level decision-making driven by institutional imperatives.
- Whilst all of the project leads had been involved in leadership roles in curriculum innovation in their own Schools and Faculties, the National HE STEM

Programme project was the first experience for many of managing a large externally funded undertaking. Those who had previously directed or managed such projects were able to draw upon that experience to act as 'change agents' to successfully broker innovation within their own institutions and across the HE sector.

- Projects were dependent on the openness and support of academic staff (and in some cases technicians) for successful implementation - though in this was not always immediately forthcoming in some cases. It was essential therefore, that those leading projects made sure that their colleagues were: clear about the benefits of the proposed changes; kept fully informed about developments; given opportunities to voice their opinions; and confident that account was being taken of their concerns.
- Projects depended on the openness and support of colleagues (including technicians) – though in a few cases though this was not forthcoming. It was essential therefore, to ensure that staff were: clear about the benefits of the proposed changes; kept informed about developments; given opportunities to voice opinions; and confident that account was being taken of their concerns.
- Projects recognised that in order to succeed they needed to secure student engagement with their development activities, not simply through representation on planning groups and through the provision of feedback, but by inviting them to become active participants in the curriculum change process - to be equal partners in a joint enterprise rather than the consumers of changes planned for and delivered to them by others.
- It was a common occurrence for project leads to encounter problems in trying to balance the competing demands on time of their on going commitments to administration, teaching and research with implementing a large externally funded project. In a number of cases this was resolved by appointing a well-qualified individual to take responsibility for the day-to-day management of the project.
- Another effective strategy for reducing the demands on project leads and teams was the appointment of external evaluators, which brought the added advantage of introducing an independent perspective through the provision of carefully researched evaluative feedback – someone to act as a 'critical friend' to the project.
- From the outset two projects were based on institutional partnerships and others were developed during the funding period. The key to successful collaboration in these partnerships rested on the ability of the partners to work amicably and effectively together as a 'community of practice'. This occurred best when the partners worked within mutually agreed plans that set out the shared strategic goals, and then identified what actions would be taken, when and how they would be implemented, and by whom.


DUB

5. Phase 2: Additional Projects

Introduction

5.1 An important part of the legacy inherited by the National HE STEM Programme from previous funding streams aimed at enhancing teaching and learning in the HE sector was the work undertaken by the HE STEM Pilot Projects (see paragraphs 3.11 and 3.14-3.17), and by the CETLs. The strategic aim of the four projects funded by the programme that were the focus of **Phase 2** of this research was to build upon the achievements of those earlier initiatives.

5.2 The four projects ('Context and Problem Based Learning', 'Group Industrial Projects', 'Maths Support', and 'Teacher Fellows')[9] were all found to be far more complex and extensive in scale than the so-called 'large scale curriculum enhancement projects' that were the subject of the research **Phase 1**. These differences were reflected in their funding arrangements, the number of HEIs involved in each project, and in their association with the professional bodies (RSC, IOP and MSOR) that had been responsible for leading there of the discipline-based HE STEM pilots.

5.3 However, despite having characteristics in common that distinguished them from the large scale curriculum enhancement projects, closer examination revealed that the four projects were also significantly different from each other in many respects including: their intended outcomes; how they were led, managed and organized; and, the number of institutions from across the HE sector actively involved in their implementation. This meant that in determining a strategy for the collection of data about them that some decisions had to be made on a case-by-case basis - whilst at the same time adhering to the same principles that had underpinned the research methods used in connection with the twelve large-scale curriculum enhancement projects (see paragraphs 4.4 and 4.5).

Data collection, processing and analysis

5.4 As in **Phase 1** the aim was to question those most directly involved in the planning and implementation of the projects – the key stakeholders - in an attempt to capture evidence derived from their particular vantage points. However, given the scale and complexity of the projects it seemed sensible to begin that process by questioning the project managers or leads with a view to gaining an overall sense of each project as a whole and identifying other significant stakeholders. Whilst the intention was to interview those individuals face-to-face wherever possible, the numbers involved and their distribution in institutions across the HE sector meant that some of the interactions would have to be conducted by telephone and through the exchange of information by email. One whole day meeting of partner HEIs in the 'Maths Support' project was attended by one of the research team in the role of participant observer.

5.5 As in **Phase 1** the interviews were conducted using generic discussion topics derived from the aims of the enquiry and its research questions. Similarly, any relevant documents that were available (e.g. project proposals, and evaluation reports) were studied in advance of the interviews so that they could be conducted from a well-informed position. This preliminary groundwork enabled the interviewers to put questions designed to address generic issues (and the answers to them) into context. The interviews varied in duration but were generally in the order of 45-60 minutes. Notes were taken during the interviews and in some cases the interactions were recorded (with the approval of those who were being questioned). The recordings were not transcribed but were used to check the accuracy of the interview notes and to identify potential quotations that might be included in this report.

5.6 All member of the team were involved in the data collection but the resultant evidence was processed and analysed in each case by a lead researcher and used as the basis for drafting the project reports given below. Those drafts, which followed a common structure, were then progressively modified and refined in the light of inputs from the other members of the team. Each of the four project reports contains a paragraph that provides details of the sources of evidence on which it is based.

Context and Problem Based Learning

5.7 In the period 2006-2008 HEFCE funded the 'Chemistry for our Future' project the aim of which was of to ensure that there was a sustainable base of chemical science within HE that would continue to attract able students from all backgrounds and provide chemical science courses appropriate for students and employers. Additional funding from HEFCE enabled the project to continue until July 2009. Aspects of that initiative have been further developed as part of the RSC's

9 For the details go to: http://www.hestem.ac.uk/activity

contribution to the National HE STEM Programme i.e. the 'Context and Problem Based Learning (CPBL)' and 'School Teacher Fellows' projects.

5.8 In broad terms, the aim of the CPBL project is to enhance the curriculum of undergraduate Chemistry students through the real-life application of the principles and techniques they encounter, and experiments they conduct, during their programmes of study. The RSC has promoted this through the development of a suite of teaching and learning resources in forensic science, pharmaceuticals, environmental science and industrial chemistry that meet the following criteria:

- Centre on authentic problems set in real industrial contexts.
- Fit into the framework provided by the RSC's 'Chemistry for Tomorrow's World' 'Roadmap' (2009)[10].
- Involve students not just in solving abstract problems but also in practical decision-making.
- Contain all of the materials required by staff and students for the flexible delivery of small 5-credit modules including guidelines on teaching and learning and its assessment.

5.9 The evidence on which this section of the report is based is drawn from a number of sources and perspectives. The former included texts made available by the RSC such as reports by those involved in the development of the CPBL resources and the External Evaluator. The latter include interviews and email exchanges with those at the RSC responsible for the central management of the project, and staff at Dublin Institute of Technology and the University of Leicester who led on the development of the teaching and learning resources that were subsequently piloted in a wide range of partner institutions across the HE sector.

5.10 There was common understanding amongst those questioned that the principal aim of the CPBL resources is to further students' employability by increasing their industrial awareness, developing their capacity for independent learning, and improving their problem solving, team working and communication skills. When questioned this was summed up by three of those responsible for developing the resources as follows: *'The basis of the CPBL project is to design resources that when used with students will: facilitate their active engagement while learning about core topics in Chemistry; and, embed the development of such key skills as problem solving, communication, information technology, experimental design and working with others.'* (Project Lead(s), Dublin Institute of Technology); and, *'Through the development of new CPBL resources the project aims to produce graduates with an improved higher level of skills which meet the needs of employers and with a greater awareness of the real-world relevance of Chemistry.'* (Project Lead, University of Leicester)

5.11 The role of RSC in the implementation of the CPBL project was to manage and support the development of the suite of teaching-learning resources by academics from HEI Chemistry departments who had successfully bid for funding provided for the purpose by the National HE STEM Programme. The following three-stage process was adopted for the development of this suite of resources:

- Dublin Institute of Technology and the University of Leicester (working in collaboration with partner HEIs) were given the responsibility for leading on the development of CPBL resource units.
- The resources developed in this way were then piloted in twenty partner HEIs – a process that included the provision of formative feedback by an External Evaluator appointed by the RSC.
- The end products (the CPBL resource units) will then be disseminated by the RSC via its website, events and other activities.

5.12 Broadly speaking therefore the implementation of the CPBL project was based on a research, development and dissemination (RDD) model. The evidence provided by the two HEIs responsible for devising the resources shows how this strategy was translated into action from their perspective. The initial research on which the resources were based consisted of: literature reviews of CPBL with an emphasis on initiatives in science subjects; planning of resource units (e.g. developing scenarios, compiling and aligning learning outcomes, planning teaching and learning activities and their assessments, conducting risk assessments for laboratory work, ordering equipment; and, liaison with the project Steering Group. The outcomes from these activities were then used in the development of the resources (i.e. guidelines and support material for tutors and students, on-line video components and wiki prompts) for each of the 'stand alone' CPBL resource units. These were then revised

10 This is based on the assumption that global changes will continue to present society with challenges relating to energy, food and the environment, and that action should be taken to address these problems. The RSC identified where the chemical sciences can provide sustainable solutions as well as promoting action and awareness in these areas. Its 'roadmap' for the chemical sciences is a guide to the future direction of chemistry research and education.

in the light of feedback provided by the External Evaluator and internal review teams prior to being trialled in-house and in partner HEIs. Evaluative feedback from the latter was used to finalise the resources so that they could be delivered to the RSC by the July 2012 deadline for the project[11]. In addition to providing an overall framework within which the development activities could take place across a large number of collaborating HEIs the RSC gave on-going support to the process e.g. in providing those developing the resources with access to information they lacked via its network of subject specialists. According to once of those questioned *'the vast membership of the RSC was at our disposal so you really had nothing to worry about; it was an incredibly useful resource'* (Project Lead, University of Leicester).

5.13 Those questioned were also positive about the impact of the project, not least because of the number of HEIs (twenty plus), which previously had made limited or no use of CPBL that had already been involved in developing and piloting one or more of the resource units e.g. *'I think the fact that we have got twenty institutions either using CPBL has been the major impact of this project so far'* (Project Lead, University of Leicester). In addition, it should be noted that the development process itself was highly collaborative - both within and between HEIs and with the RSC and its membership. Consequently, the project provided those who participated in it with an opportunity to further their own personal and professional development – not just in terms of their knowledge and understanding of the design and delivery of CPBL but in the planning and management of change. Clearly, the interactions, both formal and informal, between all those involved in the process has helped to build a strong 'community of practice' centred on important aspects of teaching and learning in chemical sciences. This can be illustrated by reference to one small example: *'Many of the initial concerns centred on the lack of experience on the use of wikis, but having used them for this project, all tutors reported that they will continue to use wikis in the future implementation of the CPBL resources'* (Project Lead(s), Dublin Institute of Technology). At this stage it is difficult to predict what the future impact of the CPBL resource units will be, but the way they have been designed in terms of their size and the user support provided by their contents should make them easy to adopt and incorporate into the programmes of study. In addition, the resource units will be actively promoted by the RSC whose 'seal of approval' (or 'kite mark') they will bear - and the Chemistry academics who have collaborated in their development will continue to be available to champion and support their use by others in the HE sector.

5.14 In terms of sustainability those who had given a lead to the development of the CPBL resources were optimistic about their future use. First of all on the grounds that they were already embedded within the curriculum of their own departments as well as in those of HEIs involved in the trials. In terms of future sustainability one of those questioned noted that: *'There was a lot of interest from the trial teams, especially in the nanochemistry and medicinal chemistry resources, reflecting a desire for context-based materials on these topics. To date, seven of the eight trial teams have completed their case study reports and have indicated that they will continue to use the materials again in the next academic session'* (Project Lead(s), Dublin Institute of Technology). It was also pointed out that the resources themselves have been designed so that new developments in the discipline can easily be incorporated into them – so that in addition to being 'off the shelf' they have been designed in such a way as to be 'future proofed'. All that said it is evident that in terms of sustaining the momentum already established in CPBL that much will depends on the continued support provided by the RSC. For example, one of those question said that: *'It will be important to ensure that the 'Learn Chemistry' site and the system by which academic staff can request the tutor material that forms part of our resources by e-mail is maintained by the RSC', and that 'the dedicated section on context and problem based learning on the RSC Education webpages is maintained as an important dissemination tool*[12]*'* (Project Lead(s), Dublin Institute of Technology). However, the question is whether in the longer term the momentum that has been established with regard to CPBL will be self-sustaining without an additional injection of funding.

5.15 Over the period 2010-12 the RSC working in close collaboration with its partner HEIs and in association with the National HE STEM Programme has successfully managed the development and piloting of a suite of CPBL resource units. It can be concluded that the success in achieving this objective can be attributed to a number of factors as follows:

- The prior research and development activity that resulted in the RSC's *Chemistry for*

11 Working to the strict timetable determined by those providing the funding was undoubtedly a source of pressure for those involved in developing and piloting the CPBL resource units.

12 http://www.rsc.org/Education/HESTEM/CPBL/index.asp

Tomorrow's World 'Roadmap' published in 2009 provided a conceptual framework within which the design and development of the CPBL resources could take place.

- As an organisation the RSC had the 'human capital' including the knowledge, experience and capabilities of its staff (i.e. its 'intellectual capital') to lead and manage the development process, and the organisational structures and resources to support them whilst doing so (i.e. its 'managerial capital').
- The RSC also has the 'network capital' (i.e. its reputation and relational links with the HE sector and with industry) that enabled it to broker participation in, and secure specialist support for, the project.
- The aims and objectives of the CPBL project were closely aligned with current departmental, faculty and institutional goals with regard to HE sector policy priorities such as those relating to students' employability.
- The participating HEIs were being invited to work within a highly supportive framework to develop small 5-credit modules, which it would be relatively easy to incorporate into their courses of study, and not to embark unaided on large-scale reform of the whole curriculum.
- The adoption of an action research approach to the development of the CPBL resources, central to which has been a planned and systematic approach to quality assurance involving: formative evaluation by the initial developers; piloting in twenty HEIs; and rigorous independent evaluation by an External Evaluator with knowledge and experience of CPBL.
- The CPBL project was temporary short-term initiative with regard to its funding, but its implementation was efficiently managed by a well-established organisation - the RSC - which for the foreseeable future will continue to maintain and disseminate the resources.
- As a result of brokering by the RSC, the development process involved a lot of close collaboration between HEIs thus building a body of expertise in CPBL as well as functioning practitioner network or 'community of practice' across the HE sector.

Group Industrial Project

5.16 A key area of National HE STEM Programme activity is upon strengthening links between the HE sector and employers[13]. This involved increasing engagement with employers' needs with a view to enhancing the curriculum, and in turn helping students to acquire the knowledge and skills required to function effectively in the world of work. The Group Industrial Projects (GIP) initiative, which began in the academic year 2011-2012, is located at the core of these issues. The scheme involves the Physics departments in nine universities adapting and rolling out a scheme that had been running successfully for 20 years as an integral part of the undergraduate curriculum at Durham University. Working in partnership with the IOP the dual aim of the project is to forge closer links between Physics departments and employers, and to increase the employability of Physics graduates by developing their skills and knowledge of work practices in industry. The scheme involves third-year undergraduate students working together in groups to solve real problems set for them by industry. This not only enables them to gain a better understanding of the needs of industry, but to acquire skills in project management, teamwork, communication, leadership, and financial management, as well as developing as Physicists. It also helps to highlight for students the range of career paths available to those with a degree in Physics.

5.17 The evidence on which this section of the report is based is drawn from a number of sources and perspectives. The former included reports by those involved in the development and implementation of the GIP initiative. The latter include a telephone interview and email exchanges with the person at the IOP responsible for the central management of the project and face-to-face interviews with the overall Project Manager (Durham University), and a Project Lead (University of Leicester).

5.18 With regard to implementation of the GIP initiative, a Project Manager based at Durham University was appointed on a part-time basis to provide advice and guidance to the participating departments, including support in finding industrial partners. Although the project was initially scheduled to end in June 2012, the IOP has agreed to support the participation of six new departments[14] in the academic year 2012-2013. It is anticipated that the scheme will be sustained as a long running component of undergraduate degree programmes in Physics after this initial period. The Project Manager's role has been extended to support the six new departments

13 See Chapter 3 Section 3.2 for a more detailed account.

14 The IOP is now working with 15 University Physics Departments in the UK: Bath, Birmingham, Bristol, Cardiff, Exeter, Hertfordshire, Hull, Lancaster, Liverpool, Leicester, Oxford, Queen Mary University of London, Surrey, UCL and York.

through the provision of bespoke guidance made available by means of telephone and email. The IOP supports the GIP project by helping universities to work together to share ideas and good practice, and by producing and disseminating guidance and advice for others wishing to participate.

5.19 Although GIP have long been an established component in the undergraduate curriculum in Physics at Durham University, few institutions across the HE sector had equivalent schemes until the provision of funding by the National HE STEM Programme. According to the IOP, the departments that have become involved in the project since that time were the ones that have found it relatively easy to develop a 'local' version of the scheme in operation at Durham. This was explained as follows: *'a lot of the departments also had a group research project as well as an individual project but it didn't have a real industrial focus; it was a lab-based project. So it wasn't hard for them to adapt that as an industrial group project.'* (IOP). It would seem therefore, that some Physics departments became involved in the project for the following reason: it was relatively straightforward for them to do so because the GIP fitted easily into the existing structures of their degree programmes; and, in terms of pedagogy it was closely aligned with the teaching and learning methods they were seeking to develop. This is illustrated by one of those questioned who stated that students in his Physics department were well placed to undertake an GIP because problem-based learning had already been strongly embedded in the degree programme. Hence, the students were able to build upon their prior experiences of working in groups gained throughout their course of study, so that this was *'really the 'icing on the cake' because they are doing it for real, they are doing it for a real employer'* (Project Lead, University of Leicester). On the other hand it was noted that there are some Physics departments that have found it find much more difficult to accommodate GIP methodology including those that currently require final year students to do a laboratory based-project. Whilst factors such as these could influence future adoption, it was suggested by those questioned that the GIP approach might yet appeal to universities across the sector because of the pressure they are under to close the gap between the knowledge and skills of their graduates and those needed by employers. In addition, by emphasising the importance of group work as a means of developing the transferable skills required by industry, the IOP *'has 'greased the wheels' or prepared the way by suggesting they do group work'*. (IOP).

5.20 Initially, it was anticipated that around 350 students would be involved in GIPs in the first year but this was, in the words of one of those questioned, *'hopelessly, hopelessly optimistic'*. In the event 75 students participated in the GIP initiative across the nine universities, with the biggest cohort being 16 students in one of the universities. It was suggested that one of the reasons for this was that the students had proved to be rather conservative, and had preferred to go with 'tried and trusted projects' rather than the more 'risky' option: *'Virtually everybody has been saying the same thing. Students are very conservative; they don't like being guinea pigs on new programmes. And if there's a choice between an established individual research project which the university has been doing for years and a completely new scheme that no other student has ever done before and no one knows how it will work, they will choose other one'* (Project Manager, Durham University). This might have been exacerbated by the fact that assessment undertaken in the third-year has a heavier weighting on the award of the final degree. Nevertheless, those questioned saw this problem as a barrier that will need to be overcome in the future because students would gain more confidence in the scheme if the GIP was to become increasingly embedded within the undergraduate curriculum. It was suggested that the timing of the introduction of the GIP initiative had also been a factor in the uptake by students noted above. When the IOP announced the scheme in 2011, Physics departments were left with very little 'lead in' time for the introduction of the project for the 2011-2012 academic year. This meant that it was difficult to progress the scheme through the university committees and then to put the idea of doing GIPs to students in time for them to consider the merits and weigh-up the options before making their decisions. Consequently, students who were already familiar with the requirement of their courses may have been seen the GIP as 'optional extras'. The Project Manager suggested that ideally a full year should have been allocated to get all the details through the committees and to ensure that the scheme was presented to students in the same positive way as the other options open to them.

5.21 As a result of the disappointingly low uptake by students most universities had to find only 3 or 4 industrial partners for the implementation of the GIP. Unfortunately, some universities contacted companies over the summer 2011 to set up the GIP scheme and then had to inform them that they did not have enough students to go ahead with all of the projects. However, as more departments become involved and student numbers increase, there is the possibility that recruitment of industrial partners could become more problematic in the future. It was also suggested by one of those questioned that in recruiting industrial partners careful consideration will need to be given to their suitability for the role. The project lead in one of the participating HEIs reported that he had been able to recruit three industrial partners for the four GIPs undertaken in his department. In so doing he had visited a range of potential partners in order to establish: the feasibility of their project proposals; and, whether those projects were capable of meeting industrial standards in the time available. These visits also helped to identify those employers who understood what an GIP was intended to achieve in terms of learning outcomes: *'I wanted people who were embracing the initiative for the right reasons, that they were involved in giving the students the skills that they themselves wanted to see'* (Project Lead, University of Leicester). In other words, departments planning to adopt GIP into their undergraduate programmes not only need to recruit the required number of industrial partners, but those who are most suited to the scheme in terms of the projects they can offer and the support they can give to the students. Finally, it was reported that the legal department in some universities raised some concerns about the interaction with industrial partners: *'This varied dramatically from university to university depending on how paranoid their legal departments were. Everything was signed off in the end but it was a major headache'* (Project Manager, Durham University). One possible way of resolving this problem would be through insurance cover in the event of any problems that arise 'downstream'.

5.22 The project lead interviewed for the purposes of the research drew attention two key areas of difficulty with regard to legal matters that it should be possible to overcome. The first problem he identified resulted from the short period of time (three weeks) that the students had been allocated to undertake their preliminary investigations and risk assessments, following their initial meetings with the industrial partners. Once work on the projects was underway it became apparent that there were health and safely issues that required further consideration and action. This has resulted in a change of procedure by which academics from the Physics department now conduct the risk assessments prior to the start of every GIP in order to ensure that everything has been covered effectively. The non-disclosure agreements required by industrial partners also caused problems when applied to the oral presentations given by students as part of the assessment of their GIP. This I matter that will need to be resolved through further negotiation - with students giving their presentations on site in the presence of the employers being a possible outcome.

5.23 Another matter that that would appear to require further negotiation with the industrial partners concerns their role in relation to the students. The evidence thus far suggests that in general there was not as much contact between students and employers as had been anticipated. Initially, the employers provided a summary of the industrial problem that was to be the basis of the GIP along with any relevant background papers. They also met with students on site at the start of the project. In theory there should then have been a contact person at the company with whom the students could liaise at all times. At the end a report was produced and some form of interaction followed during which students received feedback from the companies – though this pattern varied considerably between HEIs with some having a mid-term review. However, most of the companies reported to the project manager that they had been disappointed with the amount of interaction they had had with the students in connection with the GIP. For their part, some universities indicated that they had been concerned that it would have put companies off the whole GIP approach if their students made frequent contact with them about their projects. However, it transpired that the industrial partners would have welcomed more contact with students not less, and would have been willing to check that the work was not being duplicated and to receive reports on progress.

5.24 Networking between universities was a feature of the implementation of the GIP – meetings providing an opportunity for the sharing of ideas. There was also a Google site onto which the Project Manager had uploaded resources, and a Google forum was set up to facilitate interaction online, which in the event proved to be ineffective. Seemingly, only one of the participating universities was keen to make it work and several did not even sign up for it. The Project Manager suggested that people had been too busy to become involved, and that some of those involved in the GIP initiative may not have been accustomed to taking part in the activities of an online community. Nevertheless, she thought that it would be worth trying out this idea again because such a forum is easy to set up, costs nothing to run, and has much to offer in terms of sharing ideas and facilitating practice transfer.

5.25 According to those questioned, the methods used to assess the students' GIP varied widely, which was attributed to the fact that the group projects had been incorporated into the existing assessment procedures. In some cases therefore, assessment of the projects is incorporated into the students' poster demonstrations, whereas in others a viva is used – sometimes in combination with a poster demonstration. As a result, there is a lack of consistency in assessment methods used across the participating HEIs - although at this stage the significance of this is not yet clear. What is perhaps more important is the problems that have arisen in some departments as a result of the difficulty some academics have with the idea of including the assessment of group work in the final year of a degree programme. This has led to lively debates in teaching committees about how to assess group projects in ways that avoid individuals being disadvantaged if they find themselves in a group that under-performs for whatever reason. Whilst solutions have been 'thrashed out' by those committees it is likely that the issue of group versus individual assessment will remain a potential source of difficulties. In this context it is surprising that departments have not resorted to the use of the practices developed elsewhere including the adoption of well-tried e-tools for group and peer assessment such as WebPA[15].

5.26 In terms of the impact of the GIP project, it has now been introduced in the undergraduate programmes of almost half of the Physics departments in the UK. A survey conducted by the Centre for Evaluation and Monitoring in the School of Education at Durham University of students' attitudes before and after their GIP, indicated that they found the experience rewarding and thought in the process they had become more employable. This together with the views expressed by those interviewed suggests that the GIP has had a positive impact on the students' experience, furthered their engagement and increased their awareness of what employers will expect of them as graduates. The project lead commented the experience should boost the students' confidence when they construct their CVs and attend job interviews: *'They can hit the ground running when it comes to interviews and that will boost their confidence and for a lot of the students involved that was absolutely critical because confidence is sometimes the key missing ingredient'* (Project Lead, University of Leicester). Another of those questioned indicated that: *'It's been very well received, the students love it, and they're intending to carry on with it in the future. Everybody is saying the same thing. It's been hugely successful'* (Project Manager, Durham University). Finally, the view expressed by the IOP was that the response to the project across the HE sector has been very positive: *'It will result in almost half of the departments in the country have engaged with a new way of doing something that the IOP thinks ticks all the boxes (e.g. offering transferable skills, giving students experience of work and industry, getting departments talking to business)'*.

5.27 With regard to sustainability, the nine universities involved in the GIP project in the academic year 2011-2012 have continued in the current academic year (2012-13), alongside six additional university Physics departments that are now being supported by the IOP. The indications are that most departments involved in the project are looking to run GIPs for several more years at least, so that they in the process of becoming an established element in their undergraduate programmes. According to the GIP Project Manager, *'Nobody has suggested that they won't be carrying it on for several years'. The project lead confirmed that this was the case in his institution: 'The staff in the department are fully committed to the Group Industrial Projects and it is planned to continue to embed them within the degree programme. In addition, there are plans to extend the projects wider, into other departments/ colleges. This is facilitated by the fact that the projects are aligned with institutional and departmental policy around employability. In addition, it is helped that the project is aligned with policies of Government funding bodies, particularly in terms of their expectations of STEM graduates'*. One factor that was said to have contributed to the potential for sustainability of the GIPs is that once they have been established they can be maintained at only have a small financial cost. IOP will not provide funding for departments wishing to introduce GIPs in the future, but they will continue to broker their adoption by putting them in touch with other departments and set up meetings to facilitate the sharing of good practice. The IOP's support for the network of departments delivering GIPs will be ongoing for as long as it is required; however, it is anticipated within the IOP that some of the support structures will probably be removed once GIPs are firmly established in a range of departments i.e. enough momentum will have been built up for that aspect of the initiative to be self-sustaining.

5.28 The impact achieved by the during the GIP initiative as funded by the National HE STEM Programme can be attributed to a number of factors as follows:

- The aims and objectives of the GIP initiative were closely aligned with the current goals of Physics departments, particularly with regard to their engagement with employers and the development of their students' transferable skills and industrial awareness.
- The IOP demonstrated its ongoing commitment to the project by ensuring that effective

15 See webpa.lboro.ac.uk/

support mechanisms were available the participating departments, and pledging to continue to assist in the development of a 'community of practice' with regard to GIP beyond the end of the funding period.

- The appointment of a project manager (based in a Physics department with long experience of GIP methodology) enabled an overview to be maintained of developments across the participating Physics departments, problems to be identified and addressed in a timely manner, and for support and advice to be provided as and when required.
- The collaborative synergies between the IOP, the National HE STEM Programme and the participating HEIs and their industrial partners helped to raise the profile of the project and encouraged other Physics departments to become involved. In particular, the fact that Durham University (widely viewed as a high status institution) was willing to share its experience of GIP was an important factor in encouraging other research-intensive universities to join the project.
- The GIP initiative avoided a 'one-size-fits-all' approach - departments being allowed to adapt the GIP to the structures of their undergraduate programmes. This was especially important in relation to the modes of assessment used by different departments.

Mathematics and Statistics Support

5.29 It is widely recognised that Mathematics underpins all STEM subjects to a significant degree. However, for many students in Higher Education, difficulties with mathematics and statistics can be a barrier to the successful study of a STEM discipline[16]. One of the key roles of Mathematics and Statistics support is to enable all students of STEM subjects to achieve their full potential by helping them to develop confidence, skills and understanding in relation to mathematics and statistics. The **sigma** Mathematics and Statistics Support Network was funded by the Mathematics strand of the National HE STEM Programme through the Institute of Mathematics and its Association (IMA) to address that problem. The aim was to build on the work previously undertaken by the collaborative CETL in the provision of Mathematics and Statistics support that had been based at Coventry University and Loughborough University during the period 2005-10. Professor Duncan Lawson (Coventry University) and Professor Tony Croft (Loughborough University) co-directed the **sigma** network - with the day-to-day administration being undertaken by an Assistant Director based at the University of Birmingham. Consequently, there has been a large increase across the HE sector in support activity for mathematics and statistics as part of the response to the challenges presented by the growing intake of very diverse student cohorts with regard to their: transition from school, college or the workplace to university; retention; achievement; satisfaction; and, employability.

5.30 Maths support as used in this context encompasses the activities, facilities and resources provided in HE institutions with the aim of supporting and enhancing the learning of Mathematics or Statistics of students enrolled on their programmes of study at undergraduate or postgraduate levels - such support being non-compulsory. Being open to students as an 'optional extra' usually means that no module credit is associated with the students' engagement with supplementary learning activities of this kind. However, provision of maths support can be aligned with specific components of a degree programme that are proving troublesome, but the assistance provided in such circumstances is optional and supplementary. In general terms the aims of the 'Maths Support' project as funded by the National HE STEM Programme were to: provide students with learning environments in which they could access the support and build confidence in their ability to apply Mathematics or Statistics in their studies irrespective of their subject disciplines; conduct research into, and promote the enhancement of, the teaching and learning of Mathematics and Statistics; and, stimulate and encourage the growth of similar activity across the HE sector in the UK and beyond.

5.31 Within the context of the research as a whole Maths Support was only one of four projects to be studied in **Phase 2** following the investigations into the twelve curriculum enhancement projects in **Phase 1**. However, it quickly proved to be a very large undertaking when compared with all of the other projects in the sample both in terms of the complexity of its organisational structures and the number of participating institutions from across the HE sector. It was necessary therefore, to adopt a strategic approach to the collection of data in relation to this project, particularly with regard to the most effective use of time. Consequently, the sources of evidence on which this section of the report is based were: an interview with the Assistant Director (University of Birmingham) supplemented by the exchange of information by email; attendance as a participant observer at a one-day event attended by a wide range of delegates from across the

16 For a summary of the evidence see Fletcher, L. (2012).

sigma network (4 May 2012, Loughborough University); and, questioning by email of those who had attended the above event. Reference was also made to a wide range of documentary evidence relating to this project including: funding proposals and progress reports from HEIs; responses to questions addressed to participating institutions; research papers and reports[17].

5.32 The central task in the implementation of the project funded by the National HE STEM Programme was to establish the **sigma** Network as a free association of staff and institutions providing mathematics and statistics support that would work together to share resources and experience. Some of the main actions taken to establish and build this 'community of practice' included the following:

- Developing two central hubs (one at Coventry University and the other at Loughborough University) to co-ordinate the activities of the network including maintaining a website and publishing a quarterly e-newsletter – with the help of administrative support provided by an Assistant Director based at the University of Birmingham.
- Setting up six **sigma** regional hubs (in the North-East, North-West & North Wales, Midlands, South-West & South Wales, East Anglia and, South-East).
- Organising an annual conference on Mathematics and Statistics support in conjunction with the MSOR Subject Centre of the Higher Education Academy.
- Working with the officers of the Mathematical Sciences Societies Unit to develop and pilot mathematics support for learners in the workforce.
- Working with communities of practitioners in other disciplines to develop and disseminate subject-specific resources for Mathematics and Statistics support.
- Organising a competitive process for distributing funds (to be matched by funding from the successful institutions) to create support provision in HEIs in England and Wales, which previously had offered its students little or no Mathematics and Statistics support.

5.33 Within the broad developmental framework outlined above each of the six **sigma** regional hubs: appointed a Regional Coordinator; identified potential members of the network from within their local HEIs; promoted and hosted local maths support events; collected, analysed and reported on evaluation data; provided updates for the **sigma** network website; submitted reports to the e-newsletter; and, attended and contributed to the network's Annual Conference. It is not possible within the scope of this study to give a more detailed account of the diverse range of activities implemented by the Maths Support project[18] with the help of National HE STEM Programme funding other than to note the following:

- Experienced Mathematics and Statistics support practitioners were appointed to act as **sigma** advisors to facilitate the successful transfer of existing good practice to new centres and to further staff development in those centres by acting as mentors.
- Postgraduate training workshops (supported by a good practice booklet) in the provision of one-to-one and small group help to students seeking assistance at drop-in centres.
- The production and dissemination of publications of interest to Mathematics and Statistics support practitioners including conference papers and reports on a literature review and a survey relating to maths support provision.
- The award of **sigma** prizes for outstanding contributions by individuals (in UK HEIs or from overseas) in the field of Mathematics and Statistics support plus the appointment in 2012 of two **sigma** Visiting Fellows.

5.34 It has been suggested that prior to the advent of the **sigma** network those in the HE sector could be forgiven for regarding *'mathematics support as a form of cottage industry practised by a few well meaning, possibly eccentric, individuals, who may themselves have been hard pushed to offer a credible rationale for this work'* (Kyle, 2008). However, thanks largely to the impact of developments attributable to the **sigma** network, Mathematics and Statistics support is now firmly embedded in the delivery of higher education in the UK. It is also evident that the demand for Mathematics and Statistics support will persist on into the foreseeable future - the growth in the **sigma** network during the period of National HE STEM Programme funding (2010–12) providing evidence to support that assertion. In 2010 there were just five centres in HEIs offering mathematics and statistics support that were funded through **sigma**, but by 2012 that number had risen to

17 Advantage was taken of an opportunity (unplanned) to observe (for 40 minutes) the activities taking place in the drop-in centre at Loughborough University late on a Friday afternoon at the end of the Spring Term.

18 For a full account see Fletcher, L. (2012).

twenty-two (nine from the 2012 funding round and eight in Wales funded by the Wales Spoke of the National HE STEM Programme and trained by **sigma**). Similarly, in 2010 there were only two pilot regional hubs, but by 2012 six regional hubs had been established covering England and Wales (plus additional support networks in Scotland and Northern Ireland). Within that framework each of the HEIs that has developed a centre for Mathematics and Statistics support is currently working hard to ensure that the provision it offers will continue after the **sigma** funding ended (July 2012). It is highly significant therefore, that the impact of the **sigma** Network on the resourcing of mathematics and statistics support services is increasingly seen as making an important contribution to the widening participation and retention strategies of institutions across the HE sector. As such, explicit references are now being to be made to it in the Office of Fair Access (OFFA) agreements of universities – the **sigma** Network final report (Fletcher, 2012 p44-5) provides examples of statements that have been drawn from the agreements of thirteen institutions.

5.35 With regard to sustainability, to be eligible for **sigma** funding an institution had to agree to provide matching support, in cash or kind. Additionally, institutions receiving support from the second round of funding had to undertake to support their newly established Mathematics and Statistics support centres in the academic year 2012–3. Hence there is an understanding at an institutional level that the centres will continue to operate in the academic year 2012–3. Current activities being undertaken by centres in looking to next year include: securing better accommodation for their centres (both in terms of their location and the learning spaces they provide); gaining support from their university's Teaching and Learning Committees; and, increasing the visibility of their work amongst students and staff. This can be illustrated by reference to the National HE STEM Programme funded centre at the University of Birmingham, which set out its plans for embedding its activities as follows: *'The University proposes to enhance mathematics support provision across the University through the MSC (Mathematics Support Centre) to include peer support and mentoring, use of the MSC for outreach activities, pedagogic research and the delivery of bespoke mathematics provision within undergraduate programmes. The MSC will act as a focus for mathematics support within the University and will bring together members of staff to address issues in an integrated manner. Through embedding evaluation, the MSC will be used in a proactive manner to help understand where specific issues exist within University of Birmingham provision, and address these at source'* (Fletcher, 2012 p50).

5.36 By way of contrast to the centres, the **sigma** regional hubs were established without any undertaking regarding continuity beyond the end of the designated funding period (2010-12). In addition, the coordinators of those hubs are already heavily committed to the delivery of mathematics and statistics support in their own institutions. Consequently, any future planning and promotion of hub activities must be fitted into busy work schedules without access to additional resources. Despite that, each of the hubs has identified mathematics and statistics support practitioners who are willing to take **sigma** network activities forward in order to ensure that the regional hubs continue to operate as a means of sharing good practice. The plans already formulated for 2012-13 include: half-day 'sharing good practice' meetings; one-day development events on aspects of cross-university Mathematics and Statistics support; dissemination of the concept of mathematics and statistics support to other HEIs; and, an annual forum in the hub to discuss ideas and issues and promote collaborative ways of working within and between institutions.

5.37 As with the regional hubs funding for the national hubs and the central administration of the **sigma** network also came to an end in July 2012. However, a steering group of voluntary Mathematics and Statistics support practitioners has been established to guide and develop the network in the future, and the annual CETL-MSOR conference will be in 2013. It is unfortunate that this should coincide with the publication of the 'House of Lords Report on Higher Education in STEM' (House of Lords, 2012), which indicated that Mathematics remains a major factor that inhibits the success of those studying STEM disciplines in HE. The need for mathematics and statistics support therefore, seems certain to grow rather than diminish. The work of **sigma** within the National HE STEM Programme has established a strong and robust 'community of practice' that is already well equipped to meet this challenge. The evidence is that the commitment and enthusiasm of those within this community will ensure that many of the activities summarised in this report are sustained. However, further funding is urgently needed to build on what has already been achieved by the **sigma** network. In particular, resources are required to support the pedagogic research and evaluation that would provide the evidence on which on-going improvements in practice could be based, and in so doing help to extend and further professionalise the delivery of Mathematics and Statistics support across the HE sector.

5.38 The impact achieved by the **sigma** network during the period in which it was funded by the National HE STEM Programme can be attributed to a number of factors as follows:

- The intended outcomes of the project were clearly defined and closely aligned with institutional goals and priorities across the whole HE sector in response to the challenges presented by the intake of diverse cohorts of students with regard to their transition to university, retention, achievement, satisfaction and employability. Put simply, the primary aim of Mathematics and Statistics support is to enable all students (not just of STEM subjects) to achieve to their full potential.

- The project was able to build on the foundations established by the work of the HEFCE-funded **sigma** CETLs during the period 2005-10 (and indeed of earlier funding streams aimed at enhancing teaching and learning[19]). In particular, it was able to offer institutions across the HE sector models and related principles of good practice with regard to Mathematics and Statistics support that had already been established through rigorously conducted action research.

- At the same time it was recognised that that it was not possible to decree what form the provision of Mathematics and Statistics support should take within an HEI i.e. whilst adhering to certain core principles it has to be customised to the context in order to address the particular needs of the students.

- Whilst the primary aim of Mathematics and Statistics support was to enable students to achieve their full potential the project recognised that this could not be achieved simply through the provision of on-line resources. It required instead dedicated learning spaces (or 'centres') where students had personal access to Mathematics and Statistics support practitioners.

- Those leading the project also realised that in order to professionalise Mathematics and Statistics support and to enhance its quality it was necessary to provide opportunities for continuing professional development for staff responsible for its delivery such as training events, mentoring and good practice guides – and to draw them into the wider community of practice associated with the **sigma** network.

- During the period of National HE STEM Programme funding the **sigma** network was fortunate have as its Co-Directors two individuals who not only had the 'positional authority' that had been bestowed upon them when they were appointed, but the 'personal authority' they had earned through their long-standing commitment to the development of Mathematics and Statistics support, and with that the body of work for which they were responsible.

School Teacher Fellows

5.39 In the UK substantial changes have taken place in secondary school science education over the last two decades including: alterations to the national curriculum introduced to Year 10 students in September 2006; and, the unitisation of AS/A level syllabuses in 2000 with the further changes in 2008. These changes have resulted in schemes of work in all science subjects being *'in and out and even changed from one science discipline to another'* (Shallcross and Harrison, 2007:101). In addition, the recent announcement (September, 2012) made by the Education Secretary, stating that GCSEs will be removed and replaced with an English Baccalaureate qualification (to be introduced to year 10 pupils in 2015) in English, Maths and Sciences subjects has added further to the turbulence. The past and proposed changes mean that University Science Departments are, and will continue, to face challenges in maintaining congruence between School/FE and University year 1 undergraduate courses. In addition, University Chemistry Departments are faced with difficulties around recruitment and retention as evidenced by the closure of several Chemistry Departments[20]. Set within this context, the National HE STEM Programme in association with the RSC sought to respond to these difficulties by funding and supporting the School Teacher Fellowship (STF) scheme.

5.40 The Bristol ChemLabS conceived the STF scheme at the University of Bristol in 2005. It was further developed by the RSC, and it has been run by the society for the past five years. Over the last two years it has been funded by the National HE STEM Programme. Drawing upon previous work, the aim of was to focus on the key themes of transition, retention, outreach, recruitment and widening participation in Chemistry. The STF project therefore, builds upon previous action research including two HFCE funded pilot projects undertaken by the RSC: 'Chemistry for Our Future'; and 'Chemistry: The Next Generation' in which

19 See Lawson, D., Croft, T. and Halpin, M. (2001).

20 This has included well-established Chemistry Departments: Kings College London, Queen Mary College London, Swansea and Exeter. This is also a wider problem faced by STEM disciplines e.g. there have been closures in Physics (Newcastle) and in Mathematics (Hull).

STFs (1 or 2 per year) were established to develop resources for use in schools – the focus being on the transition from schools and colleges to HE.

5.41 The 'Chemistry for Our Future' project (2006-2008) was a HEFCE funded £3.25 million project.[21] The project aimed to ensure that the chemical sciences in HE attract able students from all backgrounds and provide appropriate courses for both students and employers in the 21st century. The 'Chemistry: The Next Generation' project aimed to inspire sixth form students to continue to study Chemistry at university by using academics and chemical industry personnel to act as mentors. In addition, the project aimed to interest students under represented in HE to study Chemistry, and to demonstrate the job opportunities available for Chemistry graduates. The 'Chemistry: The Next Generation' project was a two-year pilot study that was supported by the RSC working in collaboration with twelve universities, three pharmaceutical companies and two Sector Skills Councils. It was conducted in three regions: North West, London and East Midlands. Building on work conducted in the two pilot projects and beyond, using similar methods and selection criteria, the National HE STEM Programme funded STF scheme involves qualified and experienced secondary school teachers who have a PhD qualification, being seconded from their schools to work for twelve months in a university chemistry department. The desirable characteristics of a STF include: holding a position of responsibility in a school's middle management; familiarity with report and bid writing and the formality of meetings; and, giving presentations to their peers. In addition, it is essential that an STF has experience working with teaching staff in schools, and has strong links with outreach activities provided by the host university (Shallcross and Harrison, 2007). The STF scheme ran from 2010 to 2012 during which it appointed four STF - two during 2010-2011 and a further two in 2011-2012.

5.42 For the purposes of this research the sources of evidence have included the examination of reports, online information and academic papers. In addition a meeting was attended at the RSC[22] where discussions were undertaken with the person who had a managerial oversight of the STFs project and its Project Officer. In addition the STFs at Durham University, the University of Leicester and at the University of Manchester were interviewed face-to-face.

5.43 Because each STF was responsible for devising their own aims and objectives, their schemes of work reveal differences in terms of the key themes identified in paragraph 5.41. Interviews with the STFs showed that whilst initially they all had a set of aims towards which they wanted to work, their project planning (and subsequent implementation) was driven by: departmental policies; their prior experiences and areas of interest; desire to build on work previously undertaken by STFs; and, the outcomes of meetings with academics in the host university, the RSC and the National HE STEM Programme. This can be illustrated by two of the STFs who had studied for their PhDs in the Chemistry departments to which they were seconded. This enabled one of them to explore in advance how her ideas about the role were aligned with departmental policy priorities and the STEM Programme's criteria. The second STF explained that whilst she did have clear aims at the outset, changes to departmental policy resulted in a shift in focus[23]. In contrast, the third STF who had made connections with her university department through work as a school teacher and approached the HEI to take her on as a STF, commented that to begin with her project aims had been very broad: *'The aims were purposely set to be quite vague at the start because as a school teacher coming into a university I can't set aims until I know how things are done […] So I think that is a good thing about it because I wouldn't want everything too prescribed'*. This STF therefore, was able over time to develop the focus of her work by building on: departmental needs; work conducted by previous STFs; and, her interest in finding ways to ease students' transition from school laboratories to those in the university.

5.44 The implementation of the STF project resulted in the development of a wide range of teaching resources, good practice guides, publications, academic papers, workshops and contributions to other events. The following key outputs and successes were identified by those questioned.

- Extensive outreach activities including: annual events, such as a sixth form project week within a university department; the development and distribution of outreach resources/packs; and, outreach activities that were not just local to the host university but extended to cater for a whole region.
- The initiation of the 'Academics in Schools' project, which will be continued into the next academic year (2012-13), to include more staff members. This activity is aimed

21 There was also an additional 12-month extension phase of the project. This gained further funding from HEFCE - £1.65 million. The project ended in July 2009.

22 The meeting was held in Cambridge in April 2012

23 This was in response to a recent survey by the National Union of Students.

at improving the academics' understanding of the student experience and the teaching they have received prior to Year 1 in HE.

- A 'Model Answers' project has been piloted with the aim of easing the transition between school and university, with plans in place to continue using this approach with undergraduate students in their first and possibly second years.
- A Chemistry laboratory course manual for use with first year undergraduates has been developed and made available via the RSC's 'Learn Chemistry' website.
- A set of worksheets called 'Starters for Ten' has been devised to help teachers teach difficult topics to students aged 14-18. These have been distributed to various schools and are also available on the RSC website.
- Based on surveys of over 500 first year undergraduates, ten problem-based practical activities have been developed and trialed in a range of schools. These resources are aimed at 16-18 year olds, include all the necessary worksheets - and are being disseminated via the RSC website.
- Work undertaken by STFs has been disseminated by means of: presentations at staff training days in university departments; academic papers; and, talks to undergraduates who wish to go into teaching at careers meetings.
- In order to ease the transition from school to university teaching, work has been undertaken to investigate the delivery of feedback during lectures – work that has involved the use of whiteboards or 'smart boards' whilst lectures were in progress. The 'smart board' technology is being adapted with the view to its use in schools.
- Contributions to the RSC's development of the 'SpectraSchool' website and the establishment of a 'Teaching Advisory Board'.

5.45 Through their work in university Chemistry departments and outreach activities with schools and colleges, STFs have had a positive impact on students' transition from school to university as evidenced by: the teaching resources, case studies and good practice guides they have produced; and, the workshops they have led. However, in the main that impact has been concentrated in the host university and in local schools and colleges. One reason offered for this by those questioned was the short period of time (12 months) of each STF appointment. However, as one of them pointed out, the dissemination strategy she devised will continue to be implemented long after she has completed her secondment - and that this should help to achieve a wider impact as well as contributing to longer-term change. It is not easy at this stage therefore, to provide evidence of the full impact of the work of individual STFs let alone the scheme as a whole. For example, one STF argued that she had helped to raise the profile of teaching and learning at a departmental level, but accepted that this was very hard to measure: *'With me being here teaching and learning has been talked about a lot more, but you can't show that on a piece of paper – you can't show that as an impact necessarily.'* Another STF made the point that whilst she had undertaken a wide range of outreach activities it was impossible for her to quantify all of the changes that have occurred (and will occur over time) as an outcome of what she initiated. Nevertheless, in terms of impact in the local region, a key factor cited in one instance was the establishment of a 'Teacher Development' group, which it was argued would help to facilitate practice transfer between schools across the region. The following example was offered by way of illustration. A recent topic of discussion by the group was the development of learner independence in order to better prepare students for entry to HE. Following the meeting two schools reported that they gained funding from their Governors for extra library resources (including new Chemistry textbooks), and that a teacher had developed a series of booklets for use in schools that were similar in format to the resources given out to undergraduate students in university lectures.

5.46 During their interviews all of the STFs made positive comments about the contribution made by the RSC and the National HE STEM Programme with regard to the impact of their work. First of all, they helped by facilitating networking through the face-to-face meetings they organised, which helped to generate new ideas that built upon previous work undertaken by STFs. Secondly they provided opportunities such as national conferences and workshops for the dissemination of those ideas to a wider audience. As one STF commented: *'That [impact] just wouldn't have happened without these networks and the RSC to just get everything started… They were very keen on that, to think about the impact. Because previously it had just been within the institution and within the department.'* In addition, the RSC provided online access to a number of laboratory practical activities and worksheets, which generated widespread interest beyond the local region. The latter included an exchange of emails with a member of staff from an American School in Japan, which subsequently went on to pilot some of those resources. As far as the STFs were concerned the ability to place the resources they had developed on the RSC's 'Learn Chemistry' website has made it possible for them to achieve not just a national but also an international impact.

5.47 Although their funding ceased in July 2012 there are grounds for thinking that that much of what the STFs worked to achieve will be sustainable. In particular, the RSC website will continue to be a source of information about the issues they addressed along with the on-line resources they developed - materials that were devised with a 'long shelf-life' in mind. The STFs also plan to remain in close contact with their host university by working part-time or full-time in the Chemistry department - one having worked as Project Officer on a large-scale curriculum enhancement project funded by the National HE STEM Programme. In addition, an application for further funding has enabled a 'School Teacher Fellows Project Collaboration Group' to be established that will allow aspects of the work of STFs to be continued, and a bid has been submitted for a National Science Learning Centre 'Enthuse Cluster Award' to support the work of a 'Regional Teaching Development Group'. Finally, one of the STF questioned concluded her interview by expressing an alternative view as to how the STF initiative could not just be sustained but further developed: *'…it is a great scheme and it is a shame that it [STFs] is not continuing. But hopefully someone in the future will see the value of it and re-start it. Maybe in a different guise maybe not being Chemistry specific and being STEM specific and being you know, across all disciplines. It would probably be more appropriate now. It would be a nice evolution of the project for it not to be just in Chemistry but to move it out you know, into Engineering and things like that.'* A way forward therefore, in the event of funding being made available for the purpose, would be to build on the innovative work already undertaken in Chemistry by extending the STF initiative to other STEM disciplines.

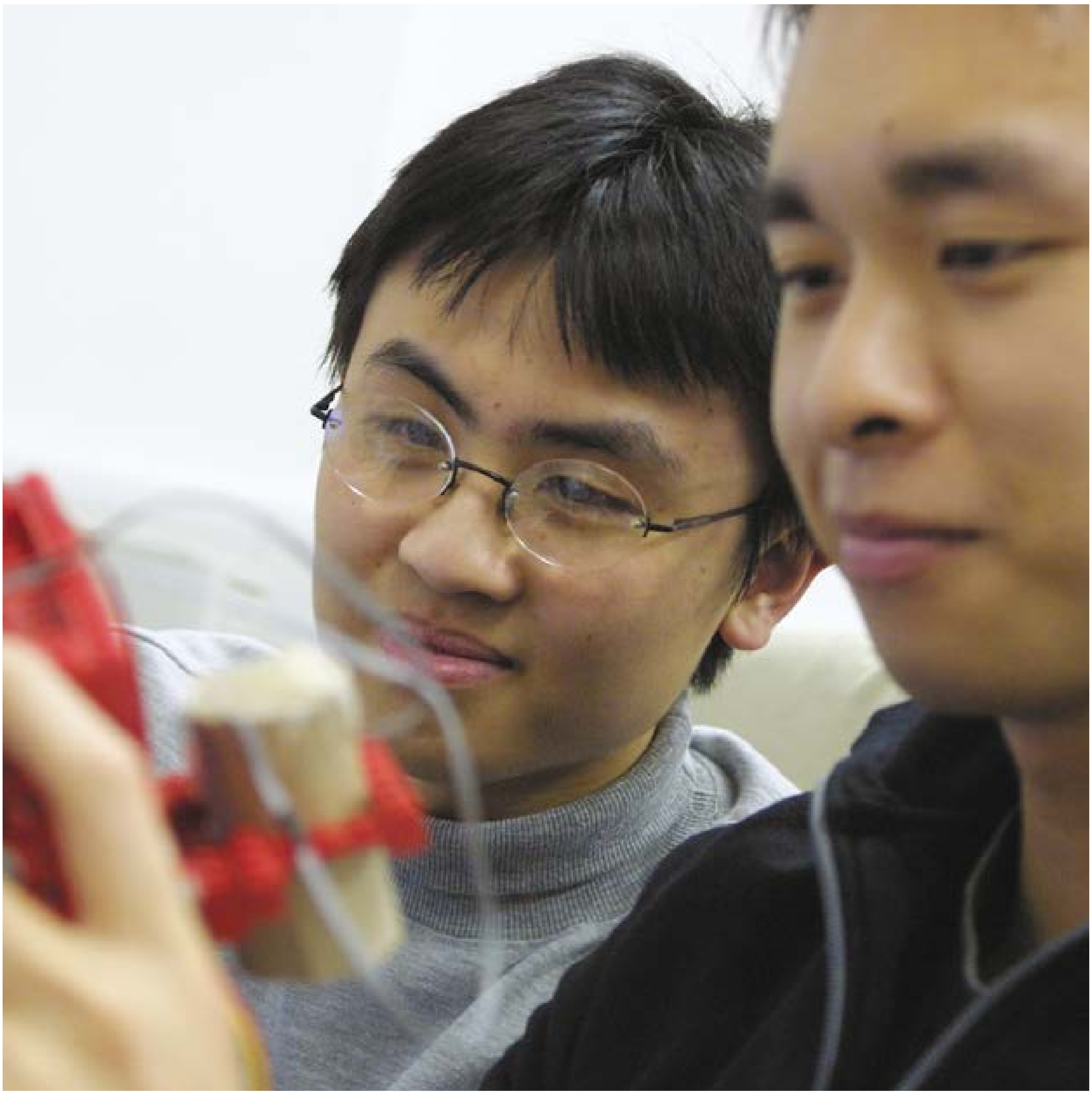
5.48 Whilst being positive about what they had achieved and about the potential of the STF role, those questioned identified a number of barriers they had encountered. One STF noted that as a schoolteacher she had found it difficult to enter a university department and make an immediate impact on professional practice with regard to teaching and learning. She attributed this to the fact that it took time to for her get established in a new environment, and to build a working relationship with academic colleagues: *'You do need to build a reputation and they [university staff] need to see that you know what you are doing and I think that [lengthening the period of time of the project] is how the scheme could be improved'.* Paradoxically, STF appointments were based on short-term (one-year) secondments so that time was always at a premium. In contrast, two STFs had both undertaken PhD study in the university departments to which they were seconded, and they both found it much easier to implement their plans. They attributed this to the fact that they had previously acquired a tacit understanding of the ways of working in the department, and were already known to key members of staff. As one STF put it: *'Because I was already known here, I wasn't a stranger […] My old PhD supervisor is still here and it was like a 'feather in a cap' if you like because people will say, 'Oh you used to work with [name of her supervisor'] and so it has been a lot easier for me, I think'.* However, whilst professional links were established and others could be made over time, there was an overall feeling that some academics were more willing to take on change than others. As one STF said: *'I still think that there are people who avoid me in corridors because they think that I'll make them do something.'* She went on to suggest that in her experience an effective strategy for dealing with such resistance to innovation is to introduce changes to the curriculum (and related working practices) slowly and incrementally.

5.49 The positive impact that has been achieved by the STF initiative can be attributed to a number of factors as follows:

- STFs were appointed who were able to facilitate change through networking and building working relationships with academics in university Chemistry departments and teachers and students in schools and colleges. The appointment of individuals to the role with previous links to the university (e.g. as post-graduate students) in addition to their teaching experience aided this process.
- The aims of the STF initiative were closely aligned with departmental and wider institutional goals and priorities with regard to recruitment as well as to students' transition to HE, retention and employability.
- STFs collaborated with their Chemistry department colleagues to create the conditions that enabled changes in professional practice to occur (e.g. by overcoming resistance by gradually introducing new materials and by demonstrating alternative teaching methods).
- The STFs funded by the National HE STEM Programme over the period 2010-12 were able to build on the achievements of previous STFs who had piloted the role when in association with the RSC. The establishment of a 'School Teacher Fellow Project Collaboration Group'

should enable the benefits to be derived from such networking to continue.

- The dissemination of resources developed by the STFs (e.g. by means of presentations at conferences, workshops, publications and via the RSC website) helped to raise the profile and increase the impact of the STF project.
- The STF and their departmental colleagues developed strategies that enabled others to collaborate and participate e.g. by means of outreach activities undertaken, not just locally but at a wider regional level.
- Whilst aligning their aims to those of their departments and institutions, the STFs were given a substantial degree of freedom within supportive environments to generate new ideas for solving problems, take calculated risks and have the self-confidence to make things happen.



6. Phase 3: Four Case Studies in Institutional Impact

Introduction

6.1 An initial 'long list' of ten HEIs was selected by the National HE STEM Programme from which a 'short list' of four would be chosen to be the subject of the following case studies. The original list was selected on the basis of the range and depth of institutional involvement with the Programme's core activities. Over the course of the research undertaken during **Phase 1** and **Phase 2** the list was reduced to four: Loughborough University; University of Leeds; University of Leicester; and, Sheffield Hallam University. A number of selection criteria were taken into consideration in making that decision including the following:

- The scale and variety of the developmental activities funded by the National HE STEM Programme that were located within each of those institutions.
- The volume of evidence that had already been collected in each of the universities for the purposes of **Phase 1** and **Phase 2** research - and hence not only how much information had already been accumulated, but the personal contacts that had been established by the researchers with individual stakeholders.
- The contrasts that were already apparent between the four as institutions of HE - and hence the potential they appeared to offer for more detailed investigation and analysis.

Data collection, processing and analysis

6.2 It had already been decided in planning the research as a whole that the data collection would be by means interviews, and that these would be in person wherever possible - telephone and email being used as an alternative and to gather supplementary information. Details of those who agreed to be interviewed in the chosen HEIs are given in each of the case study reports that follow, along the other sources of evidence that were drawn upon by the researchers. The interviews were conducted using the same generic discussion topics (see **Appendix 1**) that were derived from the aims of the investigation and used in **Phase 1** and **Phase 2**. In preparation for the interviews with stakeholder (and any meetings that were attended as participant observers) the researchers studied any relevant documents that could be assembled including project proposals, reports, case studies and journal articles. This preliminary desk research, allied to the fact that one member of the research team took prime responsibility for the data collection from an HEI, meant that the interviews were all conducted from an informed position. This helped the interviewers to put the generic questions they were asking (and the answers given to them) into context and to begin to grasp the significance of what was being said. Interviews varied in duration, but were generally in the order of 45-60 minutes. As in the other phases of the research, notes were taken during the interviews - the interactions being recorded in many cases but only after those who were being questioned had given their consent. The recordings were not transcribed but were used to verify the accuracy of the field notes and to select any significant comments and observations that could be included in this report.

6.3 Whilst all three members of the team were involved to a greater or lesser degree in the data collection relating to any one of the case study HEIs, the resultant evidence was processed and analysed in each case by a lead researcher and used by them as the basis for writing the reports given below. Their drafts, which followed a common structure derived from aims of the enquiry, were then progressively modified and refined in the light of comments made the other researchers.

National HE STEM Programme at Loughborough University

6.4 Loughborough University has approximately 18,500 students, 61% being undergraduates with the rest pursuing postgraduate courses and/or doing research. According to the 'Times Higher Education' it provided the 'Best Student Experience' for six successive years (i.e. 2006-2011 inclusive). The university is organised into ten Schools each of which has a senior management team (School SMTs) consisting of Deans, Associate Deans for Teaching, Research and Enterprise, and Operations Managers. The VC heads the university's Academic Leadership Team (ALT), which includes the Deputy VC, Chief Operating Officer, Director of Finance, PVCs for Research, Teaching and Enterprise, and Deans.

6.5 The university has a Centre for Engineering and Design Education (CEDE) the aim of which is to build on the legacy left by the Engineering Education Centre (1997-2000), engCETL (2005-

2010) and the Higher Education Academy Engineering Subject Centre or EngSC (2000-2012)[24]. It also has a Mathematics Education Centre (MEC), which housed the **sigma** - the CETL it ran in association with Coventry University (2005-10). The MEC now provides various forms of assistance for students from across the university who need help with basic mathematics and/or statistics. The university's Teaching Centre supports the delivery of teaching and learning by enhancing the student experience and helping to build a capacity for continuous improvement.

6.6 The data on which this case study is based is derived from a number of sources including texts such as project reports, case studies and journal articles relevant to the research, attendance as participant observer at three events at which National HE STEM Programme funded projects were presented and discussed, plus interviews (supplemented as necessary with the exchange of emails). The following key stakeholders agreed to be questioned for the purposes of the research: the former Manager of engCETL); the former Director of **sigma** CETL, Associate Director of the **sigma** Network and Project Lead; the former Director of engCETL and EngSC; a member of staff at the Teaching Centre; a Project Lead; the Director of CEDE and Project Lead; PVC Enterprise; and, a Principal University Teacher and Project Lead. A recurrent theme which ran through what these respondents had to say was summed up by the PVC Enterprise who stated that *'the university's response to the funding opportunities presented by the National HE STEM Programme in 2010 was a case of what we already had in the bank on which to build'*. Like many others interviewed he was making implicit use of ideas drawn from the 'intellectual capital' model (Henley Management College, 2002) to explain the situation at a time when earlier funding streams[25] that had been used to support the development of teaching and learning were coming to an end. The legacy they left was to have a profound impact on the way in which the university was able to respond to the opportunities offered by the National HE STEM Programme.

6.7 That programme funded sixteen projects based at Loughborough – with the university collaborating in another fourteen run in partnership with other HEIs[26]. In terms of funding, 'Enhancing the second year experience for undergraduate mathematicians' and 'Education for professional engineering practice' (undertaken in partnership with Sheffield Hallam University and London South Bank University) were the two largest projects - both being part of the large scale curriculum enhancement project funding initiative investigated in **Phase 1** of this research (see Chapter 4). The remaining projects at Loughborough were much smaller in scale with funding in the range £1000-£10000. Their activities were not exclusively focused on curriculum enhancement - the aim of two of them being to develop e-learning tools. Others were concerned with research (e.g. into the views of Maths graduates on their programmes of study and a survey of Maths support provision across the HE sector) the outcomes of which could be used to inform decision-making. In terms of subject disciplines almost all of the projects based at Loughborough (and those run in association with partner HEIs) were not distributed across all of the STEM subjects but were concentrated in Mathematics and Engineering. One of those projects was based in the Design School, but it was about new product design with use by engineering students as its main target.

6.8 The resources provided by the National HE SEM Programme through the above projects allowed the forward momentum already established at the university through earlier funding streams to be maintained. External support for its two CETls may have come to an end, but CEDE was in the process of being established and its Engineering Subject Centre was still operational - albeit in a reduced transitional state as new arrangements for subject support across the sector were being put in place by the Higher Education Academy. The availability of funding from the National HE STEM Programme was timely therefore, in that it allowed the university to build upon its previous commitment to, and substantial experience of: conducting pedagogic and action research; developing usable e-learning tools; enhancing student engagement; improving the curriculum; and, furthering staff development. In addition, the MEC (in association with Coventry University) was soon to be funded by the programme to lead **sigma** – a network of collaborating HEIs from across England and Wales (with offshoots in Ireland and Scotland) providing support in Mathematics and Statistics for their students irrespective of their subject disciplines (see Chapter 5).

6.9 As indicated in paragraph 6.6 the aim of two of the National HE STEM Programme funded projects was to develop e-learning tools. In both cases they were drew heavily on prior pedagogic and action research undertaken at Loughborough by PhD students (one based in engCETL and the other in the Design

24 Known originally as the LTSN Engineering Subject Centre it was 're-branded' in 2005.

25 Loughborough University had a successful record of bidding for funds from the FDTL and TQEF (see Paragraphs 3.18-3.20) as well as from JISC.

26 See http://www.hestem.ac.uk/activity

School). This enabled the projects to adopt an RDD approach – with the groundwork already done to a rigorous standard the new funding could be used on the development and dissemination of the instruments themselves rather than on the initial research. A third project based at Loughborough (' or Second Year Mathematics BeyOnd Lectures' also drew upon prior pedagogic research, which in this case had highlighted the difficulties faced by students in Year 2 of their Mathematics degree programmes. It went on to suggest how these could be addressed by means of a development strategy aimed at fostering improved relationships between staff and students, developing more engaging curricula, and by providing better learner support. In addition the development work done at Loughborough by a Project Lead as part of the 'Education for professional engineering practice' project (see Chapter 4) was based upon an earlier action-research initiative funded by one of the university's Teaching Awards. In all of these projects, the immediate availability of evaluation data from recently completed research studies had not occurred by chance. The existence of this 'intellectual capital' stemmed from strategic decisions made some time earlier e.g. by those leading engCETL and **sigma** (with senior management support from within the university) to advance pedagogic research in their respective disciplines through PhD studentships. These National HE STEM programme-funded projects based at Loughborough can be seen therefore, as a legacy (or long-term impact) of the preceding CETL initiative funded by HEFCE.

6.10 The projects funded to develop e-learning tools were also able to build on the knowledge and experience (the 'technological capital' and/or 'innovation capital') acquired at Loughborough over many years through developing such instruments as: WebPA (a web-based peer assessment system); and, the RAPID Progress File. These and other tools were developed through earlier funding streams provided by HEFCE or JISC. Given the depth and extent of this experience (and the technical knowledge that had been acquired and collaborative working practices that had been developed) it is not surprising that the two National HE STEM Programme-funded projects adhered closely to the guidance offered by JISC for what it called *'effective interventions that support e-learning practice'* (JISC, 2008)[27]. According to JISC the following factors contribute to success: usability or 'fitness for purpose'; contextualisation; promoting professional learning (i.e. developing the 'employee capital' of the organisation or the ability to respond constructively to changing needs and circumstances); working within communities; and, promoting good learning design. It was evident from the presentations given at the event run by CEDE on 11 June 2012 to showcase National HE STEM Programme activity at Loughborough and the subsequent follow-up interviews that the two projects had been implemented in working environments (i.e. those in the Engineering and Design Schools) in which the need for the e-tools had been clearly established, and in which support could be enlisted from academic staff (including senior and middle managers), technicians and students - all of whom had worked collaboratively in a mutually supportive 'community of practice'.

6.11 A recurrent theme running through what was written and said about the National HE STEM Programme projects based at Loughborough was the importance attached to furthering good practice in relation to student engagement. This should be seen in the wider context of the 'Enhancing Student Engagement' project led by the university's Teaching Centre, which has developed resources to support staff and is responsible for providing the related in-service education and training. The project is based on a broad strategic view of student engagement that encompasses: induction (or the transition from school, college and employment to HE); a 'Student Charter' (addressing issues relating to student rights and representation); and, peer support (including brokering a university-wide 'peer support community of practice'). The initiative is part of a broader institutional strategy for addressing such issues as the students' transition to HE, retention, satisfaction, achievement and employability, and as such goes well beyond providing opportunities for 'the student voice' to be heard on issues that affect them. It is based on the assumption that students should not be seen as passive recipients of a curriculum designed for them by others, but as 'change agents' i.e. as active 'co-producers' in the creation, delivery and evaluation of all their learning experiences. This perspective was strongly reflected in the following projects based at Loughborough and funded by the National HE STEM Programme: 'Stimulating student-led employer-focused activity in Engineering, Chemistry, Physics and Mathematics' (which culminated in two student-led conferences and knowledge transfer activities); 'Education for professional engineering practice' (a large scale curriculum enhancement project based primarily at Sheffield Hallam University, involving peer assessment, student mentoring and the development of a 'course community'); the library student ambassadors project; and, the

27 The typology (and the reviews on which it is based) can be found at: http://www.jisc.ac.uk/whatwedo/programmes/elearning pedagogy/elp outcomes.aspx

project (see paragraph 6.8). A Project Lead when summarising the work she had been doing to colleagues at an event run by CEDE concluded by offering them: *'One piece of advice – engage with the students'*. As with much else, the National HE STEM Programme-funded projects have been able to build upon approaches previously developed by EngSC, engCETL and MEC at Loughborough including: student representation on their Advisory Boards; membership of management committees; and, the creation learning spaces (e.g. in the building now occupied by CEDE) where students from different disciplines can work collaboratively on joint problem-solving projects.

6.12 With regard to the learning experiences offered to students at Loughborough, the availability of funding from the National HE STEM Programme enabled well-established practices and procedures for the renewal of the curriculum to be continued, and for the preferred direction in which those changes were moving (e.g. furthering learner autonomy, practical problem solving, group project work and peer assessment) to be sustained. Two of the Loughborough based projects ('Enhancing the second year experience for undergraduate mathematicians' and 'Education for professional engineering practice') were designated as 'large-scale curriculum enhancement projects' the aim of which was to impact on teaching and learning at programme and department level (Chapter 4). The latter project illustrates how this has been achieved. The aim of this project was to create an interdisciplinary learning environment that would simulate professional practice and develop the students' employability skills. It involved collaboration between the School of Electronic, Electrical and Systems Engineering and the Design School and centred on learning through interdisciplinary project work that evolved in both scale and complexity over three years of study – small group projects based on multidisciplinary topics in Year 2 leading to major group projects tackled by mixed discipline groups in Year 3 and finally individual project work in Year 4 (with fourth year students acting as mentors to those in their second year). However, as explained in paragraph 6.7 the other Loughborough based projects were smaller and more akin to the 'mini projects' offered previously through a competitive bidding process by amongst others EngSC and engCETL. The impact of these small-scale projects has been to enable those directly involved in the design and delivery of teaching and learning to enhance the curriculum through action research, and in so doing subject it to a process of continuous evaluation and renewal.

6.13 According to those questioned and on the basis of what was said during discussion at the events attended for the purposes of the research, participation in the activities associated with National HE STEM Programme funded projects provided individuals with opportunities they valued for furthering their personal development. In particular, staff at Loughborough claimed that the experience had enabled them to develop their skills in bid writing, project planning and management, report writing, evaluation, presenting and, dissemination. The process had also been one in which they had collaborated with others, both within their own Schools and in the wider university - and in some cases beyond in other institutions across the sector. That experience of working with others not only extended their personal 'network capital' but invariably involved the giving and/or receiving of peer coaching and mentoring. Access to more experienced colleagues through CEDE, the MEC and the Teaching Centre (and at events sponsored by the National HE STEM Programme) not only helped in resolving practical day-to-day issues relating to the implementation of projects, but enriched the whole experience from a professional development perspective.

6.14 In terms of sustainability the consensus amongst those interviewed was that those changes that have resulted from National HE STEM Programme funding, which have already become embedded in the curriculum will continue to be supported out of the teaching and learning budgets allocated to Schools. Indeed in June 2012 the School of Mathematics agreed to support the continuation of the student internships and mentoring scheme developed by the project and which had been central to its success. However, there was broad agreement that once external funding is no longer available it will be difficult to sustain the investment in pedagogic research, evaluation, the development of e-learning tools and other forms of scholarly activity, which in the past had provided the universities 'intellectual capital' on which new developmental activities could be based. In addition, the centres that were the forerunners of CEDE (engCETL and EngSC) and the MEC have hitherto fulfilled important national and even international as well institutional roles, and in so doing greatly extended the range and reach of the university's 'network capital'. In the absence of outside funding the challenge now facing those leading the two centres is how best to balance their internal commitments with maintaining external linkages they judge to be of continuing strategic importance to them and the university.

6.15 In conclusion, the positive outcomes achieved by the National HE STEM Programme funded activities based at Loughborough over the period 2010-12 can be attributed to a number of inter-related factors as follows:

- Earlier funding streams aimed at enhancing teaching and learning had enriched the 'institutional capital' of the university and in so doing left a substantial legacy especially in Engineering and Mathematics in the form of an operating environment in which the National HE STEM Programme-funded projects could succeed in achieving their objectives.
- That capital included the outcomes of prior pedagogic research and other forms of scholarly activity undertaken at Loughborough, which could be used as the starting point for the new projects funded by the programme including those aimed at enhancing the curriculum and developing e-learning tools.
- The prior experiences acquired through being the host HEI for engCETL, EngSC and **sigma** had enriched the university's 'human capital' and 'organisational capital' leaving it with the ability to provide effective support for externally funded projects. In particular, it was able through CEDE, the MEC and the Teaching Centre to help and advise on such matters as bid writing, project planning and management, evaluation, report writing and training student mentors.
- In addition to the provision of practical support the MEC and CEDE were able to draw upon their 'network capital' to 'broker' collaborative partnerships and to foster the development of 'communities of practice' both within the university and across the HE sector - and in so doing 'add value' to the activities funded by the National HE STEM Programme.
- The presence of individual members of staff in the university's centres and schools with the ability to act as 'change agents' as a result of: having a clear sense of purpose and strong beliefs about teaching and learning; being capable of working with others; being strategically and politically well-connected (especially to those in positions of authority); and, being proactive in seeking out opportunities to promote innovation.
- The activities funded by the programme were able to build upon approaches to student engagement that had been established previously by engCETL, EngSC and MEC and to operate within the policy/practice framework provided by the university's 'Enhancing Student Engagement' project.
- Management structures and procedures that provided an organisational framework within which the efforts and achievements of those who successfully bid for project funding were valued and supported – and in which the necessary mechanisms are in place so that the related scholarly activities can be recognised and rewarded.

National HE STEM Programme at the University of Leeds

6.16 The University of Leeds was established in 1904 having previously been a college within the federal Victoria University along with the two colleges that gave rise to the Universities of Liverpool and Manchester. It is now one of the largest HE institutions in the UK with a student population of over 33,000 (the fifth highest in the UK) drawn from 142 countries. It is a member of the Russell Group of research-intensive universities and the integration of that research into the curriculum is central to its teaching and learning strategy i.e. to provide students with courses taught by staff engaged in world-class research and professional practice. Consequently, the teaching programmes it offers are not only underpinned by research but also designed to give students at all levels the opportunity to learn about the research process and to experience at first hand how knowledge is created. According to the latest NSS (2012) 90% of its students were satisfied with the quality of the teaching they experienced on their chosen courses of study. It is not surprising therefore, that Leeds has been awarded 17 National Teaching Fellowships - more than any other HEI in England, Northern Ireland and Wales - by the Higher Education Academy. Whilst the university is highly rated across a wide range of subjects (e.g. it has more students studying languages than any other HEI in the UK) five of its nine Faculties (Biological Sciences, Engineering, Environment, Mathematics and Physical Sciences and Medicine and Health) all fall within the definition of the STEM disciplines.

6.17 The HEFCE-funded Centre for Bioscience was based at the university – from 2000-05 as the LTSN Subject Centre and from 2005-10 as the Higher Education Academy Subject Centre. In addition the university participated in five of the Centres for Excellence in Teaching and Learning (CETLs) funded by HEFCE over the period 2005-10 in order to reward and further develop excellent learning and teaching in HE as follows: the Assessment and Learning in Practice Settings (ALPS) CETL, which involved five HEIs led by the University of Leeds; the InterDisciplinary Ethics Applied (IDEA) CETL based solely at Leeds; CETL ALIC (Active Learning in Computing) involving collaboration between four universities led by Durham University; the LearnHigher CETL involving sixteen universities led by Liverpool Hope University; and, the White Rose Centre for Excellence in Teaching and Learning Enterprise (WRCETLE) in partnership with three HEIs led by the University of Sheffield. The University of Leeds therefore, already had a strong record of involvement (and the individual and collective learning experiences that went with that) in implementing HEFCE-funded teaching and learning initiatives prior to the opportunities offered by the National HE STEM Programme. It also had the organisational structures and procedures in place to support those seeking to be involved in externally-funded curriculum innovation including: clear institutional policy/practice frameworks; a Teaching Support Office (to provide guidance on matters relating to quality assurance, support for New Lecturers, practice seminars etc); a Staff Development Unit; and a unit to support the adoption and use of new technologies to enhance teaching and learning.

6.18 The evidence on which this case study is based is drawn from a variety of sources including texts such as project proposal, reports, and published material relevant to the research, attendance as participant observer at a one-day symposium the National HE STEM Programme funded 'Mathematical Modelling and Problem Solving' project held in Leeds on 28-05-12[28], plus interviews (supplemented as necessary with the exchange of emails). With regard to the latter, the following agreed to be questioned for the purposes of the research: the Pro-Dean for Student Education for the Faculty of Engineering; a Lecturer in the School of Civil Engineering; the Learning and Teaching Enhancement Officer and Project Manager of the 'Business Skills for Chemists' and 'Enhancing Employability for Maths Graduates' (plus a much smaller 'Transfer Adopters' project); and, the Project Lead for the 'Higher level skills for HE STEM students: Mathematical Modelling and Problem Solving' project.

6.19 The National HE STEM Programme funded a wide range of activities that were based at the University of Leeds - their value ranging from £500 to £45,000. In terms of the subjects referred to in their titles the projects included two in Chemistry, two in Engineering and six in Mathematics[29]. However, two of the six 'Mathematics projects' ('Mathematical Modelling and Problem Solving' and 'Enhancing Maths Support') were seeking to improve the learning experiences of students across a wide variety of levels and subject disciplines. Three of the projects ('Business Skills for Chemists', 'Enhancing the Employability of Mathematics Graduates' and 'Mathematical modelling and problem solving') were recipients of funding in the range of £30,000-£45,000 and as such were not dissimilar in scale to the twelve large-scale curriculum enhancement projects studied in **Phase 1** of this research. The data collection for the purpose of this case study (see Paragraph 6.18) was focused upon these three projects, which given their aims and scale of funding were likely to have achieved the greatest institutional impact, and to have presented the most difficult challenges with regard to their implementation and sustainability.

6.20 In terms of the problems they were seeking to address and hence their intended outcomes, the three curriculum enhancement projects that were the focus of the data collection had much in common. With regard to the 'Mathematical Modelling and Problem Solving' project those questioned cited research into the UK's mathematical needs, published in June 2011 by the Advisory Committee for Mathematics Education (ACME), which confirmed that the ability to apply Mathematics and to communicate mathematical ideas are highly valued by employers. However, that research had also indicated that these skills are often perceived to be lacking in new graduates from degree courses across the STEM disciplines. According to those interviewed the problem is not related to students' ability in Mathematics e.g. the 16-19 age-groups they have worked with in schools and colleges via outreach activities and students in their first year at university have been found to be very good at using what they have learned to work out the correct answers to familiar problems such as those set in A-level examination questions. The difficulties arise when as undergraduates they are asked to apply that mathematical knowledge in order to solve authentic problems such as those encountered in employment by engineers and other STEM subject professionals. The 'Enhancing Employability for Maths Graduates' project was designed to address a similar problem – but in this case it was subject specific rather than STEM wide. It was based on the fact that Mathematics graduates enter a wide spectrum of employment where they are expected to apply their specialist knowledge and skills to solve real-world problems - and then to communicate their findings to audiences that may not be familiar with or understand the underpinning mathematics or statistics. The aim of this project therefore, was to research and develop ways of transforming the undergraduate curriculum in Mathematics in order to enhance the students' employability including

28 Presentations were given at the symposium by representatives from the following Schools at the University of Leeds: Chemistry; Civil Engineering; Electrical and Electronic Engineering; Mechanical Engineering; and, Physics.

29 See http://www.hestem.ac.uk/activity

their communication skills. Similarly, the 'Business Skills for Chemists' project was a response to the expressed need of employers for commercially aware Chemistry graduates. Hence, the aim of this project was to develop innovative approaches for teaching employability skills for chemists within the undergraduate curriculum, and in so doing to introduce the students to such business topics as intellectual property law, regulatory affairs, quality control, ethics, and health and safety.

6.21 The aims of the three curriculum enhancement projects were said by those interviewed to be closely aligned to the strategic goals of their Schools and Faculties (as well as to those of the university as a whole) with regard to the students' experiences including their transition from school, college or work to higher education, along with their achievement, satisfaction (as reflected in the NSS) and employability. It is not surprising therefore, that in each case the proposed changes to the curriculum complied with the four criteria to which all programmes of study offered by the university are expected to conform - that teaching and learning will be: research-led (in terms of both the content and how it is experienced); provide global and cultural insights; address issues of ethics and responsibility; and, contribute to the students' employability. It is in this context that the emphasis in each of the projects on practical problem solving was said by those questioned to be part of a wider strategic shift in direction towards producing future graduates – in the case of one School individuals with *'a passion for Engineering developed through tackling real engineering problems along with the ability to work with others in order to analyse complex problems, understand the decisions that have been made and why, use Mathematical knowledge for practical purposes, and to communicate effectively using different media'* (Lecturer, Civil Engineering).

6.22 The key stakeholders' accounts of the implementation of the three projects also indicate that they had much in common. In each case the activities they had initiated were based on the outcomes of prior research directed towards eliciting a deeper understanding of the problems they were seeking to address. With the 'Enhancing Employability for Maths Graduates' project this took the form of a survey of employers in order to establish a database of their views on the employability of Mathematics graduates. This provided the evidence on which actions could be planned and implemented with regard to the design and delivery of a new undergraduate curriculum. This is being introduced progressively starting with Year 1 and then rolled out in successive years, with the Year 2 students working in groups to solve real work-based problems to be assessed by means of a 'Technical Report' and a 'Lay Report'. With regard to the implementation of the 'Business Skills for Chemists' project it was said to have been a matter of applying the same generic project management principles and ideas as follows: *'consult with employers, students and academic staff, secure their engagement and adopt the idea of group projects based on real work-based problems'* (Project Lead). The outcome was 'Chemistry: Making a Difference' - a business start up project with a social enterprise theme and a requirement to write reports one for professionals and the other for a lay audience. The 'Mathematical Modelling and Problem Solving' project also drew upon research, which in this case had investigated what was frequently referred to as the 'maths problem' i.e. the difficulty, which STEM subject students experienced in the transition from school/college to university. The research showed that despite an increase in technical proficiency, the ability of new undergraduates to apply mathematics to solve problems (as opposed to answering standard examination questions) has declined. It also showed that many first year students lack the grounding in Newtonian mechanics long seen as a vehicle for developing students' mathematical modelling and problem solving skills[30]. Armed with that knowledge those skills are being developed by Year 1 Physics students through group problem solving activities. Meanwhile, in Civil Engineering a group design project in Year 1 is being used to develop students' modelling and problem solving skills - the aim being to *'get the students excited about what they were doing rather than being strategic about learning and assessment'* (Lecturer, Civil Engineering).

6.23 Clearly there is evidence here of ideas being shared and transferred between projects and the practitioners responsible for implementing them, not just about the direction of change in relation to teaching and learning in the STEM disciplines, but also about the processes by which those changes can be achieved. One of those questioned attributed this to a culture within the Faculty of Engineering and the wider university, which encourages continuous improvement through innovation and the sharing of best practice – a process that is facilitated by the formal committee structures which provide a forum for the discussion of all matters relating to teaching and learning and help to build support for proposed changes. However, this was also said to be: *'complemented by the exchange of information and ideas through*

30 For a summary of this research see 'Higher level skills for HE STEM students: mathematical modelling and problem solving'; HE STEM news; Spring/Summer 2011; www.hestem.ac.uk

informal contacts and networks both within the Faculty and across the university especially with colleagues in Chemistry, Mathematics and Physics' (Lecturer, Civil Engineering). Another of those questioned attributed this sharing and transfer of practice in part to being involved in the National HE STEM Programme i.e. *'membership of the NE cluster provided opportunities to meet others involved in similar projects (e.g. outreach and employability) and to exchange ideas and practical advice which gave a sense of moral support and being part of a wider community of practice'* (Project Lead). The same respondent also suggested that the implementation of the two projects for which she was responsible had also benefited from having been accountable to an external source of funding in that: *'having to write interim and final reports was a driver for meeting deadlines, collecting evaluation data and sorting out your ideas'*. In the case of the 'Mathematics Modelling and Problem Solving' project being part of a wider 'community of practice' through working in partnership with academics from three other universities (Keele, Manchester, and West of England) combined with the appointment of an external evaluator provided those involved with similar opportunities for sharing their experiences and the critical examination of their ideas.

6.24 With regard to the institutional impact achieved by these three large National HE STEM Programme projects based at the University of Leeds it is important to distinguish between the changes that had already been implemented by the end of the funding period (July 2012) and those that were planned i.e. between their short-term and longer-term impact. With regard to the former, the 'Mathematical Modelling and Problem Solving' project had been implemented in Mathematics, Physics and Civil Engineering, and plans were already in place for it to be adopted in 2012-13 in Chemistry, Mechanical Engineering and Electrical and Electronic Engineering. In addition, according to those questioned, all three projects had impacted positively on students by giving them experiences that had been highly motivating. In the process of acquiring those experiences the students had also been introduced to new ways of thinking and working that has provided a foundation on which they and the staff will be able to build in the later parts of their courses. This was expressed by one of the interviewees as follows: *'by getting mathematical modelling and problem solving into the programme at such an early stage (Year 1) it will impact on the whole course all the way through to the projects the students do in Year 3'* (Lecturer, Civil Engineering). In addition, it was also suggested that the three projects have helped to highlight the importance across all of the STEM disciplines of problem solving and working with others, and have demonstrated not only how these can be integrated into the curriculum but act as a catalyst for change in the longer term. The projects need to be seen therefore, in the context of undergraduate programmes that are seeking to further the students' employability by means of an integrated approach to teaching and learning which includes practical laboratory classes, group project work that require students to investigate and solve authentic problems derived from real life situations in industry, and experience life in the workplace. As one of those interviewed indicated *'this is all part of a longer term strategic goal - to shift students towards becoming professional engineers'* (Pro-Dean for Student Education, Faculty of Engineering). It was also argued by the manager of the 'Enhancing Employability for Maths Graduates' and 'Business Skills for Chemists' projects that the wide ranging consultations she had conducted had not only helped in making practical decisions about changing the curriculum, but had resulted in some unexpected longer term benefits such as offers from employers to join School Advisory Boards, practical help in designing and delivering the curriculum, and, and authentic problems on which the students' project work can be based. Other long-term impacts referred to by those questioned included enhanced engagement with students as an outcome of the interactions that were integral to the curriculum development process, and the staff development that had occurred through collaboration in the work of the projects.

6.25 In terms of sustainability those questioned indicated that the positive response of the students as evidenced by evaluation data to their learning experiences initiated by the three project, combined with the enthusiasm and commitment of the staff responsible for delivering them has ensured their sustainability. With regard to the Mathematical Modelling and Problem Solving' project this was expressed by one of those questioned as follows in relation to the situation in the School of Civil Engineering: *'the plans are to repeat the module in 2012-13 - it is already in the 'official' timetable with a guarantee already of support from senior management, academic colleagues and students'* (Lecturer, Civil Engineering). As indicated above (paragraph 6.24) the plans were already in place to enhance the undergraduate curriculum of three other Schools by adopting the approaches developed by this project in 2012-13. In terms of meeting the costs of sustaining what has been achieved by the three projects it was argued by those interviewed that the changes to the curriculum are already embedded and as such will not be expensive to deliver – in fact they were confident that future costs could be met out of School teaching and learning budgets. They also indicated that another potential source of funding was open to them i.e. the university's 'Academic Development Fund' that provides support for curriculum development projects aligned with institutional policies and priorities with regard to teaching and learning. In addition, those who have been closely involved in the National HE STEM Programme-funded projects appear committed to maintaining the links they have established with employers and continuing to participate in the activities of the related practitioner networks both within the university and beyond.

6.26 In conclusion, the positive outcomes achieved by the three National HE STEM Programme funded projects based at the University of Leeds over the period 2010-12 can be attributed to a number of factors as follows:

- The timing of the opportunities presented by the advent of the National HE STEM Programme funding was opportune in that it coincided with reviews of the undergraduate curriculum in a number of Schools/Faculties, which indicated that changes were necessary in order to improve the students' experience in terms of their transition to HE and future employability. Consequently, support was forthcoming from students, staff and senior management for the changes initiated by the three projects.
- The culture within the participating Schools/Faculties encourages continuous improvement in teaching and learning through innovation and the sharing of best practice. This is facilitated by the formal committee structures, which provides a forum for the discussion of all matters relating to the curriculum, and by the exchange of ideas by means of informal networks (or 'communities of practice') both within Schools and across the university as a whole especially within the STEM disciplines.
- The aims of the three curriculum enhancement projects investigated for the purposes of this research were closely aligned to the strategic goals of their Schools/Faculties as well as to those of the university as a whole with regard to the students' experiences especially their future employability. The resultant emphasis in all three projects on practical problem solving was part of a wider strategic shift towards producing future graduates who are well prepared for entry to the workplace.
- In all three projects the development activities they initiated were based on the outcomes of prior research directed towards eliciting a deeper understanding of the curriculum problems they were seeking to address. This not only provided each project with an evidential base on which changes pedagogy could be planned, but helped to build engagement with employers, staff and students and their on-going support.
- The projects benefited from being accountable not just internally within the Schools in which they were being implemented, but externally to the National HE STEM Programme and to being part of wider 'communities of practice' through working in partnership with other academics including those from other HEIs. In particular, this provided opportunities for sharing experiences and for the critical examination of ideas.
- The involvement of academic staff capable of acting as 'change agents'. Typically those individuals had: a clear sense of purpose and a strong commitment to curriculum improvement; the ability to work collaboratively with others; strategic and political connections (especially to those in positions of authority); strong personal networks. They were also proactive in seeking out opportunities to further innovation and change.
- The existence in the university of a culture in which high levels of achievement in relation to teaching and learning are both recognised and rewarded – the lead for two of the National HE STEM Programme funded projects having been made a university Teacher Fellow.

The National HE STEM Programme at the University of Leicester

6.27 The University of Leicester was founded as Leicestershire and Rutland University College in 1921, became University College in 1927, and was granted its Royal Charter in 1957. It is a member of the 1994 Group of universities established to promote excellence in research and teaching, enhance the experience of students and staff and set the agenda for HE. The Times Higher Education named it the 'University of the Year 2008-2009'. The university's strategic mission up to 2015 is to: consolidate its position as one of the most inclusive of Britain's top 20 universities; become an established top ten UK university; rank in the top 150 institutions in the world; and become Britain's top university for student satisfaction and teaching quality. An important theme that underpins these ambitions is the need to undertake high quality pedagogic research in order to enhance: curricula; the delivery of teaching; student learning; the development of students' subject-specific and broad-based skills; and, students' experience.

6.28 In 2009 the University replaced its Faculty structure and with four Colleges (Arts, Humanities and Law; Medicine, Biological Science and Psychology; Science and Engineering; and, Social Science) each of which has a PVC as its Head. The University was awarded funding from HEFCE (2005-2010) for three CETLs: Genetic Education Networking for Innovation and Excellence (GENIE); Spatial Literacy in Teaching (SPLINT); and Physics Innovation (piCETL). The College of Science and Engineering's piCETL was judged to be most relevant to this study. Working in partnership with the Open University and the University of Reading, piCETL focused on: positioning Physics within a broader scientific context; curriculum innovation; the use of IT; skills development; and widening access. Along with other initiatives it enabled the department of Physics and Astronomy to establish an international reputation for problem-based learning (PBL). The work at Leicester was built upon what had been achieved by Project LeAP (Problem Based Learning in Astronomy and Physics) funded previously by HEFCE and DEL as part of FDTL (4). It was not surprising therefore, that the piCETL at Leicester developed a learning environment based primarily on PBL. In addition, improvements were made to the building occupied by piCETL in order to create 'learning spaces' (Temple, 2007) that were more conducive to a PBL approach to teaching and learning.

6.29 The Project LeAP also led to the establishment of a Centre for Interdisciplinary Science[31] (I-Science) bringing together leading academics from within the University including: Chemistry; Computer Science; Geology; Geography; Physics and Astronomy[32]; Biological Science and Medicine[33]. The Centre was originally supported by the 'Stimulating Physics' pilot project[34] (2006-2009), which was funded by HEFCE and run in association with the IOP. The I-Science project developed new degree programmes that: integrated Physics with other science disciplines: offered alternative routes into Physics; widened access; and, enhanced students' employability. At Leicester, this programme is underpinned by PBL, and in 2010-12 it was supported by the National HE STEM Programme – one of fifteen development projects and activities it awarded to the University. Those projects were centred on the following disciplines: Engineering (2); Physics (4); Chemistry (7); and, Mathematics (2). Hence, the funding was used to initiate research and development activities across the full range of the STEM disciplines within the university. The project funding awarded was variable, ranging from small (approximately £10000) to large scale (£340000+) – though the majority of the projects fell into the £20000-£30000 range.

31 This is also termed as ' Integrated Science'

32 College of Science and Engineering

33 College of Medicine, Biological Sciences and Psychology

34 The 'access' strand of the pilot study

6.30 The sources of evidence on which this case study include online text, project proposals and reports provided by the National HE STEM Programme and a report undertaken by an independent evaluator. In addition primary data was gathered by means of interviews with key stakeholders including those associated with: two of the **Phase 1** large scale curriculum enhancement (Mathematics and Physics); and, three of the **Phase 2** projects (GIP, STF, and CPBL). In addition, interviews were conducted with: an Academic Director within the College of Science and Engineering[35], and another with a Project Lead[36] (Physics) for the I-Science Project.

6.31 Whilst the projects and activities under investigation were found to have their own individual aims and objectives, collectively they addressed the key themes of the National HE STEM Programme i.e. widening participation, outreach and transition, curriculum enhancement, and workforce development. They were also congruent with the Learning and Teaching Strategies and policies of both the Colleges and the wider University with regard to: enhancing the curriculum in order to be attentive to internationalization, sustainability and the requirements of employers; developing ways of fostering student engagement with their learning and career progression; enhancing the provision, scope, flexibility, sustainability of taught programmes; improving the employability of graduates; encouraging engagement with research into learning and teaching as a means of underpinning the enhancement of educational programmes and the University's reputation in this field.

6.32 All of those questioned reported that their projects had achieved a positive impact within their respective subject departments. However, in terms of implementation the STF project in Chemistry differed from the others because it involved a schoolteacher working in the department for twelve months (see paragraphs 5.39-5.49). It is not surprising in this case that the immediate

35 This individual who has worked at the University of Leicester for a long period of time was recommended to take part in this study. He is not based within a STEM department but was able to provide information that helped to gain insights into the context of the case study.

36 The Project Lead has been the Director of the piCETL and is the Director for the Centre for Interdisciplinary Science. He is also lead for a large-scale curriculum enhancement project (Physics)

impact in the department has been relatively small because the actions taken have been predominantly 'outward' facing with the intention of changing professional practice in schools and colleges. One of the two large-scale curriculum enhancement projects - students' conceptual understanding in Physics - reported that its implementation had been adversely affected by the limited time frame within which it had operated. Nevertheless, the Project Lead was confident that its impact would increase over time: *'we have only evaluated how students' conceptions change over 5 weeks and the effects/shifts have been minimal. We now need to conduct tests to see how conceptions change over a longer period – a year, to get meaningful insights as to the success of the implementation'.* Those stakeholders with involvement in the GIP (Physics), CPBL (Chemistry), and the large-scale curriculum enhancement project in Mathematics reported a greater of impact at departmental level. In the case of the Project Lead for the GIP initiative put on record that that the experience of working as a group to solve an industry-based problem had increased the students' awareness of what employers expect of them as graduates. He went on to suggest that in turn this will boost the students' confidence when they come to construct their CVs and prepare for job interviews: *'They can hit the round running when it comes to interviews and that will boost their confidence and for a lot of the students involved that was absolutely critical because confidence is sometimes the key missing ingredient'.* The Project Lead for the CPBL project also highlighted what had been achieved through the introduction of the new 'Communicating in Chemistry' module for second year undergraduates, which was said to have filled a gap in the curriculum by providing students with an opportunity to develop their communication skills.

6.33 The I-Science programme, which was originally established in 2006, was said to have had an impact across the university by building on the previous work on PBL done under the aegis of FDTL (4), piCTEL and 'Stimulating Physics' (IOP). It was said to have done this by extending its scope to other disciplines including Biological Science, Chemistry, Computer Science, Geography and Geology. The influence of GENIE and piCETL on the impact achieved subsequently by I-Science was explained by the Academic Director for the College of Science and Engineering as follows: *'It is clear that GENIE and the piCETL have been enormously influential in all sorts of ways, […] there is the PBL that did exist, but it was sporadic and I think that the I-Science programme has really brought that to the fore and because in the I-Science programme you have so many departments contributing, it has been a very natural way in which good practice is shared. So I think that those [GENIE, piCETL and I-Science] have had an important impact upon the university – and I mean that in a most positive way.'* The lead for I-Science added to what has already been noted said about its impact as follows: *'it [I-Science] involved 48 academics and 7 other people from the university in delivering this programme and we have core staff that also interact with other departments […] the acceptance of PBL in Chemistry would not have happened had they not seen how it had worked in I-Science, so they have some confidence in how the experiment works before trying it within their context […] in terms of developing a profile for teaching and confidence building to try out new things, I think that we have had an impact.'* In turn, the adoption of PBL by the Chemistry department influenced the decision to participate in the CPBL project: *'So that [PBL] has been quite useful you know, the fact that we can do something that can really push the boundaries of what you can do in a Chemistry degree. We thought that this 'underpinning science' - a key theme underpinning the Chemistry Interfaces: From Hamburgers to U-boats STEM Project - was a really nice theme that lets you show just how far how the Chemical Sciences reach outside the conventional Chemistry box'* (Project Lead, CPBL).

6.34 According to its lead I-Science also has the potential to impact on the College's Learning and Teaching Strategy by raising the profile of those staff committed to teaching, and in so doing contribute to the changing the institutional culture: *'There are discussions going on about how we can use the experience for I-Science to develop a strategic view about the relationship between teaching and research within the university […] In this department [Physics] we use academic staff much more sparingly and are replacing them with people who have proper teaching qualifications, who think about their teaching […] So if you roll it out it is 'win, win' because the teaching gets better and the research gets better because you have an appropriate division of labour and you stop viewing people who are interested in teaching as second-class citizens because they are making a contribution to research within the university in a different way'.* The university has already rewarded individuals who have been committed to enhancing teaching and learning - two National HE STEM Programme Project Leads[37] having gained Teacher Fellow status in 2012. The lead for I-Science also indicated that whilst its interdisciplinary focus had helped to further its

37 The two staff members were based within different Departments: one in Chemistry and the other in Physics.

institutional impact, it was the development of the underpinning pedagogy that has driven change – an argument that illustrates how long-term change can be achieved by building on previous funding initiatives: *'So if there was to be a legacy of I-Science it is not necessarily the interdisciplinary nature of it - it is the joined up pedagogy that is the key thing. It is not different bits of things here and there, it is a joined up way of doing things […] I think that potentially could have a huge impact upon the university.'* I-Science therefore, has had an impact across the university through the development and dissemination of PBL, which in turn helped to prepare the way for the Chemistry department's involvement in the CPBL project.

6.35 The Project Lead for the GIP initiative argued that embedding PBL into the programmes of study in Physics and Astronomy had increased the students' ability to respond positively to other changes such as working with others to solve problems devised for them by industry. He noted that a key 'driver' in relation to that project was that the intended outcomes were closely aligned with those set out in the College of Science and Engineering's Learning and Teaching Strategy, and university's key policy priorities. He went on to say: *'There is nothing about these [IG] projects that should be reserved for Physics students, because they involve real employers who will be employing Mathematicians, Physicists, Chemists, Engineers, Geographers and even outside the College. I think that having mixed teams across the College and maybe eventually across the University will be extremely desirable.'* In addition, the large-scale curriculum enhancement project in Physics has created video-screen casts to aid students' conceptual understanding – a successful innovation that has been transferred to the CPBL project in Chemistry, and the e-assessment project in Mathematics. With regard to the latter, a feature of the project has been the partnership it has established with a software company (MapleTA) which agreed to: loan staff to Leicester for one day per week to support IT delivery; and, assist in the development of an e-assessment questions bank. Plans are also in place for other departments in the College of Science and Engineering (along with the Economics department) to pilot the software that has been developed, and a university-wide e-assessment group has been established to facilitate the sharing of experience and practice transfer.

6.36 The shared view amongst the stakeholders questioned was that the changes implemented through the projects funded by the National HE STEM Programme at Leicester would be sustainable. They argued this on the grounds that since the main development costs had already been incurred, and that the new curricula were now embedded into programmes of study, it should be possible to sustain the innovations in teaching and learning by means of departmental and College budgets. It was also noted that some of the projects (notably CPBL, GIP and STF) had been implemented in association with professional bodies (RSC and IOP) that will continue to: promote them by means of conferences and workshops; and, make their outputs available on their websites. Changes will also be sustained and improved through the collaborative activities of the 'communities of practice' that have been established in the university such as: the 'School Teacher Fellows Project Collaboration Group'; the 'Regional Teaching Development Group' that will be funded by a National Science Learning Centre 'Enthuse Cluster Award'; and, the university e-assessment group. The legacy left by earlier initiatives such as the piCETL and I-Science programme in the form of a core team of experienced staff will also help to sustain the changes that have been achieved by maintaining a website and organising dissemination events. The potential for the pedagogy and resources developed by projects to be transferred to other departments and Colleges in the University was another factor identified that should contribute to sustainability especially as cross-departmental approaches are closely aligned with College and University policy.

6.37 In conclusion, the positive outcomes achieved by National HE STEM Programme funded activities based at the University of Leicester over the period 2010-12 as outlined above can be attributed to a number of inter-related factors as follows:

- The intended outcomes of the activities funded by the National HE STEM Programme investigated for the purposes of this research were consistently aligned with the strategic goals of the College (and its constituent departments) in which they were based as well as to key policy priorities of the university particularly with regard to the students' transition to HE, retention, achievement and employability.
- The structural reorganization of the university to a collegiate system has not only encouraged the development of inter-disciplinary and multi-disciplinary approaches to the design of programmes of study and research, but also the transfer between departments of ideas and resources relating to teaching and learning in general but especially with regard to PBL.
- Earlier funding streams aimed at enhancing the quality of teaching and learning had left the university with a substantial legacy or 'institutional capital' (especially in Chemistry and

Physics) in terms of the accumulated knowledge and experience of individuals and groups about pedagogy and the planning and management of change, and the networks (or 'communities of practice') that had been established both within the university and beyond. This contributed to the development of an organisational culture within which the National HE STEM Programme-funded projects could achieve their intended outcomes.

- The status of teaching and learning has been raised within the university and its importance has been recognised by the reward given to its staff for outstanding contributions - two of the leads of projects funded by the National HE STEM Programme having been the recipients of University Teacher Fellowships in 2012.
- Successful partnerships were brokered between projects based at the university with professional bodies (notably the IOP and RSC), an IT software provider, industrial organisations, and academic departments in other HEIs. The collaboration resulting from these partnerships helped to facilitate the successful implementation of planned changes to the curriculum, the impact achieved by those development activities, and their on-going sustainability.

National HE STEM Programme at Sheffield Hallam University

6.38 Sheffield Hallam University is a post-1992 university, which has a student population of approximately 25,000 undergraduates and 8000 postgraduates. The university is divided into four faculties: Faculty of Arts, Computing, Engineering and Sciences (which includes Engineering & Technology and Mathematics & Statistics); Faculty of Development and Society; Faculty of Health and Wellbeing (which includes Biosciences); and Sheffield Business School (formerly known as the Faculty of Organisation and Management). In the 2012 university league tables, The Guardian newspaper placed Sheffield Hallam 83rd out of 120 UK universities compared with 68th by The Independent, 69th by The Times and 64th by The Sunday Times.

6.39 The university has a Centre for Science Education (CSE), which is a research and business development unit specialising in the STEM subjects, but with a particular emphasis on science. Based within the CSE is 'The Women in Science, Engineering and Technology (WiSET)' team, which aims to address the under-representation of women in the STEM disciplines. CSE is a hub for regional STEM activity, housing the Regional Science Learning Centre, SETPOINT South Yorkshire and has close partnerships with the Regional STEM Support Centre, National Centre for Excellence in Teaching Mathematics (NCETM) and secondary initial teaching training at Sheffield Hallam University. The Learning and Teaching Institute, which is part of Learning and IT Services, provides a focus for supporting learning developments within the University through research, staff development, curriculum development projects and educational research. The institute's direction is determined by the university's Learning Teaching and Assessment Strategy and by its involvement with activities undertaken

6.40 The evidence on which this case study is based is derived from a variety of sources including texts such as the original project proposals submitted to the National HE STEM Programme, reports, and published material relevant to the research, plus face-to-face and telephone interviews (supplemented as necessary with the exchange of emails). With regard to the latter the following key stakeholders agreed to be questioned for the purposes of the research: a Professor of Engineering Education who is Vice Dean and Head of Learning, Teaching and Assessment for the Faculty of Arts, Computing, Engineering and Science and Project Lead for the 'Education for professional engineering practice' project; a Senior Lecturer in the Department of Mathematics and Project Lead for 'Improving feedback in HE mathematical courses'; a Principal Lecturer in the Department of Mathematics who is Project Lead of the 'Career mentoring scheme for mathematics students', 'Developing employer engagement in STEM through career mentoring', 'Developing Graduate skills in HE mathematics programmes', and 'Engaging with employers' projects; the Project Manager of 'Women in SET' and 'Careers case study'; and, the Project Manager of 'Women in SET', 'Her Story Inspiring Engineers' and 'Student STEM Ambassador Training' projects.

6.41 The National HE STEM Programme funded fourteen projects based at Sheffield Hallam University. With regards to subject disciplines four of the projects were in mathematics, four were in engineering, one was in chemistry and five were STEM wide. Nine of the projects were led by university academics; the five remaining projects (based in WiSET, Student and Learning Services, and Secondary Science ITE) were led by non-academic staff. The projects addressed a range of educational issues, including those given priority by the National HE STEM Programme relating to employability, widening participation, outreach and pedagogical innovation. Most, if not all, of the projects were built on the prior activities of individuals and teams. Some of the projects were enhancements of activities that were already in place (i.e. additional support for existing activities) whereas others were entirely new activities. In latter case therefore, the funding provided by the National HE STEM Programme was used to stimulate the development of something that was not previously there. It was suggested by one project lead that some people might find it to be surprising that Sheffield Hallam University had such a large number of projects funded by the National HE STEM Programme given that the degree programmes offered by the university in the STEM disciplines are more limited than in some institutions (e.g. the university no longer has a Physics department and does not offer the full range of structural engineering).

6.42 However, several factors at Sheffield Hallam University were said to have led to its success in relation to securing funding for projects from the National HE STEM Programme. First, the environment at the university was said to be receptive to these kinds of activities across the entire breadth of STEM provision. In part this is reflection on the fact that as a post-1992 university, Sheffield Hallam has traditionally placed a great deal of emphasis on learning and teaching; as noted above, the university has a Teaching and Learning Institute and a number of people are fully funded to support research into teaching and learning activities. Second, senior management support was also said to stem from external forces including the growing concerns with the student experience in the light of the advent of tuition fees, league tables based on employment statistics and national initiatives to widen participation across HE in general and HE STEM courses in particular. In this context, the projects that were funded at Sheffield Hallam University were linked to key strategic policies and priorities at the university and this meant that they had very strong senior management support. This can be illustrated by reference to projects relating to employability: *'SHU has for many years had a focus on providing graduates ready for employment and hosted the employability CETL. The environment at the university was not just conducive to me becoming involved in the HE STEM programme, it was actively supportive of my doing so'* (Project Lead). Another project which was run under the auspices of Women in SET was linked to wider work in the university in relation to the Athena SWAN Charter, a UK wide equality challenge unit initiative to encourage universities to sign up to good principles around the recruitment, retention and progression of women in SET in the HE sector. This project was aligned with a university-wide and departmental focus on Athena SWAN Principles: *'Athena SWAN has been an excellent way of getting top down commitment. There is not only a capacity but also an ethos and a culture which supports Women in SET work'*. Thirdly, most of the projects funded by the National HE STEM programme built on, developed and/or supplemented existing activities which were closely aligned with Sheffield Hallam University's policies and strategies: *'It built on what we were doing before, […] it provided time and resources and a catalyst for action'* (Project Lead).

6.43 There was little interaction between HE STEM projects at the university, including those that were based in the same faculty. No formal structures were set up to facilitate the sharing and cross-fertilisation of ideas. Informal contacts did occur through individuals meeting each other during the course of their other duties, however there is no evidence to suggest that this led to ideas being systematically shared and transferred between projects and the individuals responsible for them. The projects appear therefore, to have functioned as separate entities or clusters (operating under the direction of a unit or individual academic). One Project Lead observed: *'this was a bit of a disappointment. […] However, it's an odd thing but you often make closer contact in other universities than you do with those in your own. […] When you look at the outputs you are often surprised about things that have been going on that you are not aware of. So, for example, we have people in design engineering and in science education and we are not really talking to each other. So there are lessons we can learn about talking to each other and learning from each other and raising our own awareness about what's going on'*. Interestingly, several of those consulted noted how the National HE STEM Programme funding had supported networking with departments in other universities i.e. to build and participate in wider 'communities of practice' distributed across the HE sector.

6.44 Generally speaking the projects by the Programme have led to sustainable impacts in terms of, for example, developing on-line resources, shaping university strategy documents, developing programmes that in time will be validated and accredited, and contributing to the university's submission to Athena SAWN for a silver award in relation to its commitment to advancing the careers of women in STEM in HE. However, the fact that by and large the projects operated in 'isolation' means that the impact of the National HE STEM programme at an institutional level has to be viewed in terms of what was achieved by individual projects. Project leads and project managers were able to clearly articulate the impacts of their own projects, but were only just beginning to identify and gauge the impacts and achievements of others. At the time of the interviews the broader cumulative impact of the different strands of activity funded by the National HE STEM Programme remained unclear.

6.45 The following conclusions can be drawn from this study of National HE STEM Programme funded activities based at Sheffield Hallam University over the period 2010-12:

- The long-standing commitment of Sheffield Hallam University's senior managers to activities designed to enhance teaching and learning created a culture, which encouraged staff to successfully apply for funding from the National HE STEM Programme.
- Many of the staff that applied for funding were engaged in on-going activities related to key strategic priorities at Sheffield Hallam University, the National HE STEM Programme being viewed as a means of further developing and consolidating those activities. The projects therefore, were able to build on a legacy inherited from previous investments in teaching quality enhancement.
- All of the projects were closely aligned with institutional priorities and policies at the university and enjoyed executive support throughout.
- The projects were not integrated within a holistic framework designed to facilitate the sharing and transferring of ideas during the planning, implementation and reporting phases of the projects. The projects therefore, involved relatively distinct strands of activity, which operated with little (if any) interaction with each other.
- The individual projects appear to have largely accomplished their aims and objectives and have had substantial positive outcomes, which will assist in achieving Sheffield Hallam University's strategic goals and priorities in relation to provision in the STEM disciplines.
- The National HE STEM Programme provided a vehicle through which staff could progress and supplement a range of existing activities designed to enhance the university's provision in the STEM subjects, and to meet the challenges faced by the university in this area. However, the funding does not appear to have been used to facilitate the establishment of internal networks of practitioners focused on sharing ideas for improving practice, and developing new projects that would have drawn upon the accumulated experience and expertise of its staff.

7. Conclusions

Introduction

7.1 This final chapter of the report offers a synthesis of the conclusions that have been drawn from across all three phases of this investigation, and in so doing seeks to address the questions that have provided the focus of the research. Accordingly, consideration is given to the following issues (though not necessarily in the same sequence or under the same topic headings): the success of activities funded by the programme in the HE sector with regard to achieving sustainable curriculum change; the outcomes that stakeholders particularly value; the factors that have contributed to success - or otherwise; the impact that has been achieved; the extent to which HE staff including senior managers have been engaged in the development process; how the learning that has been acquired will be utilised more widely; and, the value attributed to the work of the programme by those in the HE sector.

7.2 In reaching the conclusions that are set out below, use has been made of theoretical constructs drawn from the literature on change in the HE sector. This makes it possible to connect the issues that have emerged from the research to the wider body of thought about educational change in HE - as well as providing a series of lenses through which to examine a large amount of qualitative data. The constructs that have been found to be especially useful for this purpose are: the idea of society (and its constituent institutions) moving rapidly from a 'solid' to a 'liquid' stage of modernity (Bauman, 2000); the 'ecological university' (Barnett, 2011); 'intellectual capital' as applied to organisations such as universities (Henley Management College, 2002); 'brokerage' and 'change agency' (Jackson, 2003); and, 'communities of practice' (Wenger, 1998). These concepts were discussed earlier in the report (see paragraphs 3.1 and 3.21-3.28) and reference has been made to them at various points in the text as appropriate.

7.3 It has been argued (Field et al. 2009; Jackson, 2002; and, Barnett, 2011) that HE does not function as a 'closed system' that is sealed off from the external influences exerted by the wider society – a society that is now subject to persistent and complex change, and in which people and institutions are in a state of transition. Indeed during the lifetime of the National HE STEM Programme (2010-12) the HE system continued to experience some fundamental changes in the external environment in which it operates, and to which it was compelled to respond. This was very much in evidence during all three phases of data collection undertaken for the purpose of this research (spring-summer 2012) when issues such as the impact on recruitment of the increase in student fees, and the levels of graduate unemployment were but two of many concerns occupying the minds of those being questioned. In addition, there was widespread recognition that the successive funding streams aimed at enhancing the quality of teaching and learning in HE (what one speaker at a project event described as 'the years of plenty') were coming to an end. In discussing the conclusions that can be drawn from this research, reference will be made where appropriate to the impact on, and implications for, the HE system of these changes.

Conclusions

7.4 Evidence drawn from across all three phases of the research shows that the intended outcomes of the projects and initiatives funded by the programme were clearly defined, demonstrated a strong sense of purpose and as such were in close alignment with the goals and policy priorities of the institutions in which they were located. This was undoubtedly a reflection of the way in which the HE system is seeking to respond to the challenges presented to it not least by changes in its operating environment with regard to student recruitment, diversity, transition to university, retention, satisfaction, achievement, and employability. Put simply, the underpinning aim driving the suite of developmental activity that was the subject of this research was to enable the diverse cohorts of students entering HE to study STEM subject disciplines to achieve to their full potential.

7.5 Given the importance that is now being attached to students' transition to HE it was only to be expected that many of the activities funded by the programme were directed towards arriving at a better understanding of how the 16-19 curriculum is defined, transacted and assessed as well as seeking to build improved relationships with schools, colleges and employers, and to enhance the experiences of students once they have entered university. Although not central to the remit of this investigation, the success achieved by the most notable initiative that was sampled (the STF project) rested on: well-founded action research that built upon prior developmental activity undertaken in association with a long-established professional body; and, the appointment of individuals who were suitably qualified for the role, and capable of working effectively in a university environment as well as with teachers in schools and colleges. The model that was developed and piloted by this project over a four-year period for Chemistry could be applied equally well to other STEM disciplines and in institutions across the sector. However, such initiatives need to be seen within the framework of wider strategies for improving student recruitment, transition, retention and achievement, and the creation of organisational structures and processes that facilitate change.

7.6 The projects funded by the programme provided evidence of a discernible shift in pedagogy towards problem based learning and group and individual project work allied to stronger links with industry. Changes such as these to the curriculum of the STEM disciplines are indicative of a general movement in HE towards what has be described as a 'pedagogy for uncertain times' (Barnett, 2009: 126-138). Whilst students and those responsible for delivering them might regard these changes as 'risky' (Barnett, ibid: 139-150), they are necessary if students are to be better prepared for living and working in a 'liquid age' (Bauman, ibid). Put simply, this notion involves HE taking an 'ontological turn'. So, as well as aiding students to acquire knowledge and skills relevant to their future employability, the emphasis is on helping them to become 'somebody' such as Mathematician, Chemist, Physicist, or as one of those interviewed put it a *'passionate engineer'*. This personal, ontological development dimension includes the acquisition by students of dispositions that will prove to be valuable to them as learners over the life course (e.g. a will to learn and engage, a preparedness to listen and explore new ideas, a determination to persist in the face of difficulty, and an openness to new experiences), and learner attributes (e.g. integrity, resilience, self-discipline, self-confidence, and respect for others)[38]. This shift also represents a movement in the HE sector towards the notion of the 'ecological university' – an institution that is better suited to the unfolding, and as yet unknown demands of the future. It is to be hoped that funding can now be found to: further the development and dissemination of these approaches to teaching and learning in the STEM disciplines; and, and for the evaluations studies and pedagogic research that will provide the knowledge and understanding on which future curriculum innovation can be based.

7.7 The change in emphasis with regard to the direction of curriculum innovation that was discerned in the projects funded by the programme did not manifest itself in top-down management-led reforms of whole programmes of study in the STEM disciplines. The large-scale changes they were seeking to achieve were the products of actions taken by individuals and groups who had an awareness of the need for change combined with the ability to draw upon their collective 'innovation capital' to create and implement imaginative solutions to problems in relation to the design and delivery of the curriculum. The learning experiences of students were being gradually transformed therefore, by the cumulative effect of initiatives aimed at enhancing the curriculum in particular modules that would have a 'knock on effect' on others as part of a practitioner-led process of continuous renewal at the centre of which are individuals who are not only capable of brokering change but are part of the 'employee capital' of their institutions.

7.8 Nevertheless, the support received by programme-funded projects from senior managers was found to have been a key factor in successful implementation - even when experienced individuals were leading them. That help was especially important when project leads and their teams were seeking to: obtain additional funding; secure 'buy-in' from internal and external partners; implement planned changes within short time scales; expedite high level decision-making; and, deal with unexpected problems. Senior management involvement in the actual implementation of projects fell into three categories: direct participation as project leads or as members of teams; practical support and encouragement by individuals who were external to the management structures of projects (e.g. Heads of School and/or Directors of Undergraduate Studies); and, support from those functioning at a university-wide level (e.g. PVC Teaching and Learning). Of course, those operating at the highest level were largely responsible for providing the leadership that created the institutional frameworks within which development projects can flourish, including determining the strategic priorities with regard to the curriculum and creating a culture in which teaching and learning is valued and where outstanding contributions to its improvement are recognised and rewarded.[39]

7.9 Although curriculum innovation is dependent on inputs from senior managers and individuals who are capable of brokering change, it is essentially a collaborative activity in which those leading developmental initiatives rely on the support they receive from others. It is important therefore, that project leads in association with senior

38 The case is made in paragraph 7.11 for a similar paradigm shift in thinking about 'student engagement'.

39 This has been demonstrated in the award of Teacher Fellowships to a number of staff members working on projects funded by the programme.

managers do everything they can to ensure that their colleagues (including technical and other support staff[40]) are all: clear about the benefits of the proposed changes; kept fully-informed about developments; have access to evaluation data; given opportunities to suggest ideas and voice their opinions; able to engage in a dialogue about potential problems and the means by which they can be overcome; confident that their points of view and concerns and are being taken into account throughout all of the stages in the life of a project; and, where appropriate fully involved in planning and implementation.

7.10 Successful curriculum development is a socially constructed process[41] - the change being integrated into the minds and value systems of those involved in it. Like the acquisition of knowledge, the innovation is uniquely transformed during the process - it becomes the 'shared property' of those who have worked on it together. Participation in the development activities associated with projects funded by the programme therefore, provided both individuals and groups with opportunities to work within 'communities of practice' and in so doing further their own professional development. In particular, they were able to improve their skills in: bid writing; project planning and management; report writing; evaluation; and, dissemination. However, observation at project meetings for the purposes of this research showed that the benefits of such professional collaboration went well beyond resolving immediate practical issues relating to the implementation of curriculum change. It extended the 'network capital' of the participants, facilitated practice transfer between individuals, groups and institutions, and provided opportunities for the sharing of tacit knowledge and skills through role modelling, and for the giving and receiving of peer coaching and mentoring. The cumulative impact of these learning experiences undoubtedly enhanced the 'human capital' that is part of the legacy left by the National HE STEM Programme.

7.11 It would be unreasonable to expect students to respond positively to every attempt at curriculum innovation - especially when they have been challenged to think and do outside of the 'comfort zone' provided by familiar ways of working. Indeed research shows that students can respond in a negative manner, not just to their experience of engagement with issues concerning their individual learning, but also with HEI structures and processes (Trowler and Trowler, 2010). Thus, it was interesting to find that some of the projects funded by the programme sought to avoid the possibility of an adverse reaction from students to changes in teaching and learning by facilitating their learning transitions (Mackenzie, 2011), and inviting them to become active participants in the development process from the outset. In other words, to be collaborative partners (or 'co-producers') with the project team in a joint enterprise rather than passive consumers of changes planned for them and delivered to them by others (McCulloch, 2009). This was accomplished through joint membership of working groups, and the creation of procedures by which students could contribute to the design and delivery of the curriculum e.g. by helping to develop new teaching resources, and working as interns and mentors. The following benefits were said to have accrued from the adoption of such an approach: student perspectives were incorporated into the change process from the outset; commitment to the revised curricula was increased; and, students' experiences and achievements were enhanced. Like the shift in pedagogy, student engagement should be seen in its wider context the response of the HE system to change i.e. as an integral part of broader institutional strategies for addressing such challenges as the students' transition to university, retention, satisfaction, achievement and employability. As such it goes well beyond simply providing on-line opportunities for 'the student voice' to be surveyed on issues directly affecting them. The outstanding work undertaken by some projects in the areas of student engagement and learning support (especially in relation to Mathematics and Statistics) are an important part of the legacy of the National HE STEM the programme from which the whole sector can learn. However, research into student involvement in shaping the design and delivery of teaching and learning is limited, and there is an urgent need for new qualitative studies that will further our knowledge and understanding of the nature, function and quality of their engagement with curriculum development and educational change.

7.12 The individuals appointed to lead projects funded by the programme had varying degrees of experience with regard to directing such initiatives - this being the first experience for many of managing an externally funded project. They soon discovered that the requirements of leading a project funded by the programme presented them with new challenges including: coping with the additional workload; meeting externally-imposed deadlines; coordinating activities with university colleagues (and in some cases partner HEIs); and, addressing funding requirements with regard to evaluation,

40 Students would have been added to this list but for the fact that engagement with them is dealt with separately in paragraph 7.11.

41 This was much in evidence at the meetings and events attended by the researchers as participant observers as well as in the data collected by other means.

dissemination and reporting. In cases such as these the support of senior management was especially important - a number of those questioned reporting that they had benefited from the informal mentoring provided by more experienced colleagues. This was certainly evidence of this in the project meeting that were observed as well as in the interview data. However, the majority of project leads would have benefited from more formal guidance on project management and governance such as the guidelines produced by the FDTL, JISC and other funding initiatives. Those guidelines offered sound advice on all aspects of project management including planning, evaluation, dissemination, and risk assessment. In the event, the experience of leading a project provided what for many was a rich form of 'on-the-job training' through which they acquired transferable skills in project management, thus adding to the 'managerial capital' of their institutions, and with it an enhanced capacity for further innovation.

7.13 By way of contrast, some individuals occupying leadership roles in projects funded by the programme had long, varied and successful experience of directing externally funded projects, including those supported by the FDTL and TQEF initiatives[42]. Over the two years of the National HE STEM Programme funding period many continued to prove themselves capable of acting as 'change agents' i.e. to successfully broker innovation not only within their own institutions, but in others across the HE sector. The past and present achievements of these individuals (or 'master change agents') indicate that they possess a number of shared characteristics including: clarity of purpose; strong commitments to improving the quality of teaching and learning based on evidence derived from pedagogic research; creativity in envisioning solutions to problems; capability with regard to making decisions and taking action; the ability to build and actively participate in 'communities of practice'; being strategically well-connected; and, having the capacity to learn (and to help others to learn) from experience[43].

42 Prior experience of leading externally funded projects did not in itself guarantee successful implementation of projects – such Project Leads also required the support of senior managers and their other colleagues.

43 The metaphor 'multi-skilled anthropologist' (Barnett, 2003:xviii) is useful in this context. This involves: an understanding of 'inside' needs and requirements; a comprehension of the language, politics and positioning of different parties; representing perspectives of parties in a meaningful way, to reach mutual understanding; advancing ideas and representing perspectives of parties in a meaningful way, to reach mutual understanding; advancing ideas and developing thinking; communicating the benefits; creating and developing infrastructure to advance change that is sustainable in the future.

They are also highly successful when it comes to disseminating ideas and promoting success (as evidenced e.g. by the workshops they have led, presentations given at conferences and their lists of scholarly publications) - as well as being proactive when it comes to taking advantage of development opportunities that arise such as those offered by the Programme. The attributes these project leaders brought to the programme and used to its advantage were the product of long engagement in teaching quality enhancement over the course of successive funding streams – the 'human' and 'managerial capital' that was already 'in the bank'. Their departments and institutions will no doubt continue to benefit from their capacity to broker change, and hopefully some means will be found to for their expertise to be shared with others from across whole sector.

7.14 Many of the projects funded by the National HE STEM Programme were based upon HEIs working in partnership with each other – sometimes in association with a professional body such as the IOP, MSOR and RSC. This was clearly seen as a means of furthering the development process, facilitating practice transfer, advancing professional learning and building 'communities of practice'. However, the evidence suggests that the success of these collaborations rested on the partners being willing and motivated to work with each other, and agreeing to do so within a common framework for the management of the whole initiative that took the form of mutually agreed project plans. The most effective of those plans set out clearly and unambiguously: the aims and objectives; the actions to be taken; when and how those actions were to be implemented; who was responsible for what; and, how the outcomes would be evaluated and disseminated. Such plans enabled development activities to be coordinated across the partner institutions, which in turn facilitated the open and systematic discussion of issues and the sharing of experiences at project meetings. They also helped to counteract problems arising from differences in perceptions about intentions, divisions of labour, scales of activity and rates of progress achieved in the partner institutions, and misunderstandings about roles and responsibilities. The functioning practitioner networks or 'communities of practice' that have grown out of these partnerships in the STEM disciplines in institutions across the sector are part of the Programme's legacy.

7.15 In the opinion of many of those questioned for the purposes of this research it was still early to make definitive statement about the full impact of the large scale curriculum enhancement projects within their own institutions let alone on the wider HE sector – because as one project lead suggested *'the best is yet to come'*. Nevertheless, it is evident that many of the projects have been catalysts for deep-seated changes in their schools and faculties and that many of the curriculum innovations they have initiated are transferable both within the host institutions and to others across the sector. There was also broad agreement amongst stakeholders that their projects had achieved a wide range of positive outcomes many of which underpinned the curriculum changes that had been implemented with a view to improving the students' transitional experiences, retention, achievement and employability. These outcomes include: the stimulation of critical reflection about teaching and learning by both staff and students (e.g. through face-to-face meetings and the use of on-line blogs); enhanced understandings of student learning needs for living and working in a 'liquid age'; new ways of engaging with students and supporting their learning; increased involvement of students in the design and delivery of the curriculum (e.g. as mentors); improved feedback to learners; opportunities for staff development through participation in planning and managing innovation; wikis that offers ideas and practical advice; improved team working in relation to the design and delivery of teaching and learning; and, the development and consolidation of practitioner networks (or 'communities of practice') within institutions and across the HE sector. The full impact therefore should be seen not just in terms of curriculum enhancement, but also in the value that has been added to the employee, managerial, organisational, process, network and innovation capital (i.e. the 'intellectual property capital') of departments, institutions and the sector as a whole.

7.16 With regard to the sustainability of what had been achieved by their projects the stakeholders questioned were generally optimistic - despite acknowledging that the HE sector is facing an economically uncertain future. A number of arguments were advanced to support the view that many of the changes that had been initiated would be self-sustaining in that they no longer required input of funding comparable to that already received from the programme. In other words, the greatest expense had been incurred in meeting the initial development costs. Where changes have been embedded into programmes of study they can now be sustained out of school and faculty teaching and learning funds. The on-going support of senior management, staff and students for project-led innovations was also identified as a factor that will also help to ensure their on-going sustainability. In addition, those projects enjoying the support of professional organisation such as the IOP, MSOR and RSC fully expect the teaching and learning resources they have developed to continue to be made available to others via their websites. However, it was recognised that it may well be difficult in future to sustain certain activities in the absence of new sources of external funding including participation in 'communities of practice' through attendance at workshops and conferences that incur travel and other expenses, thus inhibiting practice transfer and limiting the professional development opportunities open to staff. Similarly, it seems likely that financial constraints will not only impose limits on the funding of curriculum enhancement initiatives, but on pedagogic research. Such research provided the 'intellectual capital' on which many of the curriculum enhancement projects were based, most noticeably in the case of the project (Loughborough University), 'Mathematical Modelling and Problem Solving' (University of Leeds) and 'Maths Support'. Similarly, some projects benefited from being able to buy in additional human resources such as project officers, external evaluators and STFs - none of those questioned expected such practices to be sustainable. The National HE STEM Programme was able to build on over two decades of investment in teaching quality enhancement funding of various kinds and the consensus was that forward momentum that this had generated across the sector would become increasingly difficult to sustain.

7.17 Whilst the research unearthed some notable examples of projects in which evaluation had played an important role in providing evidence of impact and furthering the development process, it was equally evident that evaluation could have been used more widely and effectively had its role been better understood and its potential recognised. Much greater clarity was needed about the purposes served by project evaluation, especially the need to distinguish between evaluation for: accountability (measuring results, establishing value for money); development (providing feedback to strengthen innovations); and, knowledge (obtaining evidence that leads to deeper understanding). In this context, it would have been appropriate for the focus to be on the contribution that evaluation could make to the effectiveness of the change process through the provision of formative feedback. The success of projects in achieving their intended outcomes could have been enhanced by the adoption of more systematic approaches to the planning and implementation of evaluation within a wider framework of the strategic and operational plans developed by projects (see paragraphs 7.12 and 7.14). Such evaluation plans could have been developed with the help of tools like RUFDATA (Saunders, 2000), which were widely used in the evaluation of the CETLs and Higher Education Academy Subject Centres. What the RUFDATA tool does is to focus attention of project teams on seven key questions as follows: Reasons and purposes (Why evaluate?); Uses (What use will it have?); Focus (What evidence will it collect?); Data and evidence (What kinds of evidence will it use?); Audience (Who is it for?); Timing (When will it take place?); and Agency (Who will do it?). Implicit in this recommendation is that projects should also be encouraged to adopt an action research approach to their developmental activities. This should not only enhance the outcomes, but also provide the evidence on which scholarly activities such as conference papers and future pedagogic research could be based and enrich the whole process from a staff development perspective.

8. Acknowledgements

The authors would like to express their appreciation for the help and support they have received in the conduct of the research from the following:

Dr Esat Alpay (Imperial College London); Professor Simon Biggs (University of Leeds); Dr Duncan Borman (University of Leeds); Professor Mike Bramhall (Sheffield Hallam University); Centre for Engineering and Design Education (Loughborough University); Dr Adam Crawford (Loughborough University); Professor Tony Croft (Loughborough University); Jill Collins (Sheffield Hallam University); Dr Chris Dewdney (Portsmouth University); Professor John Dickens (Loughborough University); Dr Bridgette Duncombe (Bath University); Denise Eaton (Sheffield Hallam University); Dr Maurice Fitzgerald (Loughborough University); Dr Declan Fleming (University of Bath); Dr Michael Grove (Birmingham University); Dr Dawn Hadden (Sheffield Hallam University); Dr Ella-Mae Hubbard (Loughborough University); Dr Andrew Hughes (Durham University); Professor Malcolm Joyce (Lancaster University); Dr Jennifer King (Durham University); Dr Joe Kyle (Birmingham University); Dr Fiona Lamb (Loughborough University); Professor Duncan Lawson (Coventry University); Dr Jeremy Levesley (University of Leicester); Dr Claire McDonnell (Dublin Institute of Technology); James McNish (IOP); Amanda Middleton (RSC); Rosalind Onions (RSC); Dr Samantha Pugh (University of Leeds); Professor Derek Raine (University of Leicester); Dr Katherine Rawlinson (Sheffield Hallam University); Dr Jacqui Robinson (Durham University); Dr Michael Robinson (Sheffield Hallam University); Professor Steven Rothberg (Loughborough University); Professor Mike Savage (University of Leeds); Dr Michael Seery (Dublin Institute of Technology); Dr Chris Short (Sheffield Hallam University); Dr Catherine Smith (University of Leicester); Dr Rick Thomas (University of Leicester); Dr Kirsty Turner (University of Leicester); Dr Jeff Waldock (Sheffield Hallam University); Dagmar Waller (University of Birmingham); Dr Dylan Williams (University of Leicester); Dr Peter Willmot (Loughborough University); Dr Graham Wynn (University of Leicester)

9. List of Abbreviations

BIS	Department for Business, Innovation and Skills
CETL	Centre for Excellence in Teaching and Learning
C&IT	Computer and Information Technology
CPBL	Context and Problem Based Learning
CPD	Continuing Professional Development
DEL	Department for Employment and Learning (Northern Ireland)
DfEE	Department for Education and Employability
DfES	Department for Education and Skills
DIUS	Department for Innovation, Universities and Skills
DTI	Department for Trade and Industry
ESRC	Economic and Social Research Council
FDTL	Fund for the Development of Teaching and Learning
FE	Further education
GIP	Group Industrial Project
HE	Higher education
HEA	Higher Education Academy
HEFCE	Higher Education Funding Council for England
HEFCW	Higher Education Funding Council for Wales
HEI	Higher education institution
HEQC	Higher Education Quality Council
HESDA	Higher Education Staff Development Agency
ILT	Institute for Learning and Teaching in Higher Education
IMA	Institute of Mathematics and its Applications
IOP	Institute of Physics
JISC	Joint Information Systems Committee
LTS	Learning and teaching strategy
LTSN	Learning and Teaching Support Network
MSOR	Maths, Stats & OR Network
NCT	National Coordination Team
NTFS	National Teaching Fellowship Scheme
NUS	National Union of Students
OFFA	Office of Fair Access
PVC	Pro vice-chancellor
QAA	Quality Assurance Agency for Higher Education
RAE	Royal Academy of Engineering
RSC	Royal Society of Chemistry
SIVS	Strategically Important and Vulnerable Subjects
STEM	Science, Technology, Engineering and Mathematics
STF	School Teacher Fellow
TLTP	Teaching and Learning Technology Programme
TQA	Teaching Quality Assessment
TQE	Teaching Quality Enhancement
TQEF	Teaching Quality Enhancement Fund
TRLP	Teaching and Learning Research Programme
UfI	University for Industry
UK	United Kingdom
VFM	Value for money
VLE	Virtual Learning Environment

10. Bibliography

Arber, S. (1993) The Research Process. In Gilbert, N. (ed.) (1993) *Researching Social Life*. London: SAGE Publications, pp.32-50.

Barnett, R (2003) Forward in *Engaging and Changing Higher Education through Brokerage* England and USA: ASHGATE Publishing Limited (p.xvi-xix).

Barnett, R (2009) Knowing and Becoming in Higher Education. *Studies in Higher Education* vol 34 (4) pp.429-440.

Barnett, R. (2011) *Being a University* London and New York: Routledge.

Bassey, M. (1999) *Case Study Research in Educational Settings*. Buckingham, Philadelphia: Open University Press.

Bauman, Z. (2000) *Liquid Modernity*. Cambridge: Polity Press.

Becher, T. and Trowler, P, R. (2001) *Academic Tribes and Territories* (Second edition). Buckingham, Philadelphia: SRHE and Open University Press.

Browne Report (2010) An Independent Review of Higher Education Funding and Student Finance: Securing a Sustainable Future for Higher Education. Published 12 October [online] Available at: http://www.bis.gov.uk/asses/biscore/corporate/docs/s/10-1208-securing-sustainable -higher-education-browne-report.pdf. [Accessed September 2012]

Bryman, A. (2004) *Social Research Methods* (Second edition). Oxford: Oxford University Press.

Cohen, L., Manion, L. and Morrison, K. (eds.) (2000) *Research Methods in Education* (fifth edition). London. New York. Routledge Falmer.

Creswell, J.W. (1998) *Qualitative Inquiry And Research Design: Choosing Among Five Traditions*. Thousand Oaks, California: SAGE Publications.

Dearing, R. (1997) *The National Committee of Inquiry into Higher Education* (NCIHE). London: Department for Education and Skills.

Doyle, W. and Ponder, G. (1977) The practicality ethic in teacher decision-making. *Interchange*, 8(3), 1-12.

Drever, E. (1995) *Using Semi–Structured Interviews in Small–Scale Research. A Teacher's Guide*. SCRE.

Edvinsson, L. and M.S. Malone (1997). *Intellectual Capital*. London, Piakus.

Field, J. Gallacher, J. and Ingram, R. (eds.) (2009) *Researching Transitions in Lifelong Learning*. London and New York: Routledge.

Fletcher, L. (2012) The Mathematics Support Community of Practice: A report of the achievements of **sigma** within the National HE STEM Programme; pp 7-8.

Foskett, N. Roberts, D. and Maringe, F. (2006) Report of a Higher Education Academy funded research project 2005-2006. [online] Available at: http//www.highereducationacademy.ac.uk.4407.htm [Accessed September 2010].

Fryer, R. (1997) Learning for the twenty first Century. First report to the National Advisory Group for Continuing Education and Lifelong Learning. London: NAGCELL1.

Gillham, B. (2000) *Case Study Research Methods*. London and New York: Continuum.

Henley Management College (2002). *Skills in Engineering: The landscape of change over the next twenty years*. A report by Henley Management College on behalf of the Engineering Employers' Federation.

Jackson, N. (2002) Pressures for Curriculum Change. Learning and Teaching Support Network (LTSN) Generic Centre [online] Available at: http://www.glyndwr.ac.uk/pd/new-mods3/papers/pressures for curriculum change. pdf. [Accessed June 2012].

Jackson, N (ed.) (2003) *Engaging and Changing Higher Education through Brokerage* England and USA: ASHGATE Publishing Limited.

Kennedy, H. (1997) Learning Works: Widening Participation in Further Education. Coventry: Further Education Funding Council.

Kvale, S. and Brinkmann, S. (2009) *Interviews: Learning the Craft of Qualitative Research Interviewing* (Second edition). Los Angeles, London, New Delhi and Singapore: SAGE Publications.

Kyle, J. (2008) Affordability, adaptability, approachability, and sustainability. In: Responding to the Mathematics Problem. The Maths, Stats & OR Network, Birmingham, pp. 103–4, [on line] Accessed 2 August 2012.

URL http://www.mathcentre.ac.uk/resources/uploaded/mathssupportvolumefinal.pdf

Lawson, D., Croft, T. and Halpin, M. (2001) Good Practice in the Provision of Mathematics Support Centres. Report, LTSN Maths, Stats and OR Network.

Leich, S. (2006) Leich Review of Skills. London: Department Innovation, Universities and Skills.

Mackenzie, H, E. (2011) Students' Experiences of Academic Play within Transitional Space in Higher Education. Unpublished PhD. The University of Nottingham.

Mandelson, P. (2009) Speech at the CBI Higher Education Summit, London. [online]

Available at: http:// www.news.bbc.co.uk/1/hi/education/8316658.stm. [Accessed June 2012].

McCulloch, A. (2009) The student as co-producer: learning from public administration about the student university relationship. *Studies in Higher Education*, vol 34 (2) pp 171-183.

Merriam, S, B. (1998) *Qualitative Research and Case Study: Applications in Education*. San Francisco: Jossey-Bass Publishers.

Miles, M, B. and Huberman, A, M. (1994) *Qualitative Data Analysis: An Expanded Sourcebook* (Second edition). Thousand Oaks, California, London and New Delhi: SAGE Publications.

Saunders, M. (2000) Beginning an evaluation with RUFDATA: theorising a practical approach to evaluation planning; in Evaluation, 6, 1, pp 7-21.

Scott, P. (1995) The Meanings of Mass Education in Higher Education. Buckingham: SRHE and Open University Press.

Shallcross, D.E. and Harrison, T.G. (2007) A secondary School Teacher Fellow within a university chemistry department: The answer to problems to recruitment and transition from secondary school to university and subsequent retention? *Chemistry Education Research and Practice* vol 8 (1) pp.101-104.

Silverman, D. (2005) *Doing Qualitative Research*. (Second edition) London, Thousand Oaks California, New Delhi: SAGE Publications.

Stake, R.E. (1995) *The Art of Case Study Research*. California: CA: SAGE.

Sullivan, P.H. (2000). *Value-driven Intellectual Capital*. New York, John Wiley & Sons.

Temple. P. (2007) Learning Spaces for the 21st Century: A review of the literature. [online] Available at: http:// www.heacademy.ac.uk/assets/documents/research/Learning-Spacesv3.pdf. [Accessed May 2010].

Tight, M. (2003) *Researching Higher Education*. Berkshire, England: SRHE and Open University Press.

Trowler, V. and Trowler, P. (2010) Student Engagement Evidence Summary. The Higher Education Academy.[online] Available at http:// www.heacademy.ac.uk/.../studentengagement/StudentEngagementEvidenceSummary pdf. [Accessed July 2012]

Wenger, E. (1998) *Communities of Practice: Learning meaning and identity*. Cambridge: Cambridge University Press.

White Paper (2011) Higher Education Students At The Heart Of The System. Published 28 June. [online] Available at: http://discuss.bis.gov.uk/hereform /white paper/. [Accessed July 2011].

Yin, R. (1994) *Case Study Research: Design and Methods.* (Second edition) Beverley Hills CA.: SAGE Publications.

11. Appendix 1: Interview Topic Guide

1. PROJECT DETAILS

Title:

HEI:

Partner institutions/other organizations involved:

Project Lead Name:

Names of other stakeholders:

2. PERSONAL DETAILS

Name:

Job Title:

Role in relation to the STEM-funded curriculum enhancement project:

Other roles:

Previous experience of involvement in curriculum development including internally funded and externally funded projects:

3. PROJECT AIMS AND OBJECTIVES

Problem(s) seeking to solve/Situation attempting to change:

Aims:

Objectives:

Extent to which these goals were aligned with departmental, faculty and or institutional policies/priorities:

4. PROJECT PLANNING AND PREPARATION

Strategic planning:

Operational (or action) planning:

Staff involvement and support (including senior management):

Individual or groups that on reflection could/should have been drawn into the process:

Difficulties (and tensions) that had to be addressed at the planning and preparation stage:

5. PROJECT IMPLEMENTATION

Activities that have been undertaken

Progress that has been made towards achieving the project's intended goals (milestones and outputs)

Challenges/difficulties that have had to be faced (e.g. budget, scope of the work, difficulties with partners)

Planned activities not yet implemented

Dissemination strategy

Activities already undertaken (e.g. website, seminars, case studies)

Planned activities

Evidence of progress

Evaluation strategy

Evaluation methods

Progress made towards the implementation of those plans

6. IMPACT

Project's key successes/achievements:

Tangible outcomes from the project for STEM within the HE particularly with regard to achieving sustainable practice/change

Unintended outcomes (if any)

Impact of project's work on the practices of the HEI(s) involved at module, programme, departmental, faculty and/or institutional levels (i.e. the 'buy-in')

Influence of project's work on wider practices in HE with regard to curriculum innovation, the delivery of teaching and learning or development of usable objects

Key outcomes that others in the HE sector particularly value

7. SUCCESS FACTORS

Factors that have helped the project to achieve its intended outcomes and those which have made it difficult for the project to achieve its planned goals

(Examples: funding and support from National HE STEM Programme; leadership, senior management support, resources, and value placed on the activity and drivers for change within the HEI; subject networks and wider collaboration/communities of practice)

Effective approaches and methodologies for achieving successful large-scale curriculum change and how they might be effectively fostered and supported

8. SUSTAINABILITY

Progress made for ensuring the sustainability of the project's activities beyond their initial HE STEM funded lifetime e.g. continuance, embedding within HEI activity, mainstreaming

Support for those activities including funding

Plans for utilizing the outcomes of the project more widely both within the HEI and beyond

9. WIDER PROGRAMME

Synergies through links with other HE STEM programmes, partnerships with other HEIs including awareness raising and collaboration that has been initiated.

Support received/asked for from the National HE STEM Programme.

10. ADDITIONAL COMMENTS

Authors

Professor Harry Tolley (BA, MA, PhD, PGCE) is an Honorary Professor in the School of Education at the University of Nottingham. He was the External Evaluator to engCETL and the Higher Education Academy Engineering Subject Centre (EngSC) based at Loughborough University and currently works as an independent research and evaluation consultant. He can be contacted by email at harry.tolley@nottingham.ac.uk or by telephone at 0115 8372733 (mobile 07947661723).

Professor David Greatbatch (BA, PhD) is a Visiting Professor at Durham University Business School and an Honorary Professor in the School of Education at the University of Nottingham. Alongside his academic activities, he acts as an independent research and evaluation consultant to a wide variety of organizations in the private, public and not-for-profit sectors. He can be contacted by email at david.greatbatch@durham.ac.uk or by mobile on 07800994765.

Dr Helen Mackenzie (BSc, MA, PhD) graduated as a mature student in Biological Science and has an MA in Research Methods in Education. Her PhD was based on research funded by the ESRC into aspects of the students' experience of transition within HE. She recently completed a research project at the University of Leicester into the students' experience of feedback. Alongside her academic activities, she acts as an independent research and evaluation consultant. She can be contacted by email at mackenzie.helen@gmail.com or by mobile on 447504193094.

The National HE STEM Programme

The National Higher Education Science, Technology, Engineering and Mathematics (HE STEM) Programme was a three-year initiative funded by the Higher Education Funding Councils for England and Wales through an activity grant to the University of Birmingham in August 2009. The Programme co-ordinated its activities through six geographical regions represented by the Universities of Bath, Birmingham, Bradford Manchester Metropolitan, Southampton and Swansea, and by working in collaboration with four Professional Body Partners: The Institute of Mathematics and its Applications, The Institute of Physics, The Royal Academy of Engineering, and the Royal Society of Chemistry.

Working across the higher education sector in England and Wales, with a particular focus upon the disciplines of Chemistry, Engineering, Mathematics and Physics, the Programme supported higher education institutions in encouraging the exploration of new approaches to recruiting students and delivering programmes of study. It enabled the transfer of best practice across the higher education STEM sector, facilitated its wider adoption, and encouraged innovation. Through collaboration and shared working, the Programme focused upon sustainable activities to achieve longer-term impact within the higher education sector.

ISBN 978-1-909557-02-4

Published by
University of Birmingham STEM Education Centre on behalf of the National HE STEM Programme
University of Birmingham
Edgbaston
Birmingham, B15 2TT
www.hestem.ac.uk

UNIVERSITY OF BIRMINGHAM

STEM Education Centre

National HE STEM Programme

This document has been produced by the University of Birmingham STEM Education Centre as part of its ongoing commitment to disseminating the learning arising from the National HE STEM Programme.