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Engaging students in research and inquiry: with particular reference to STEM disciplines

Keynote

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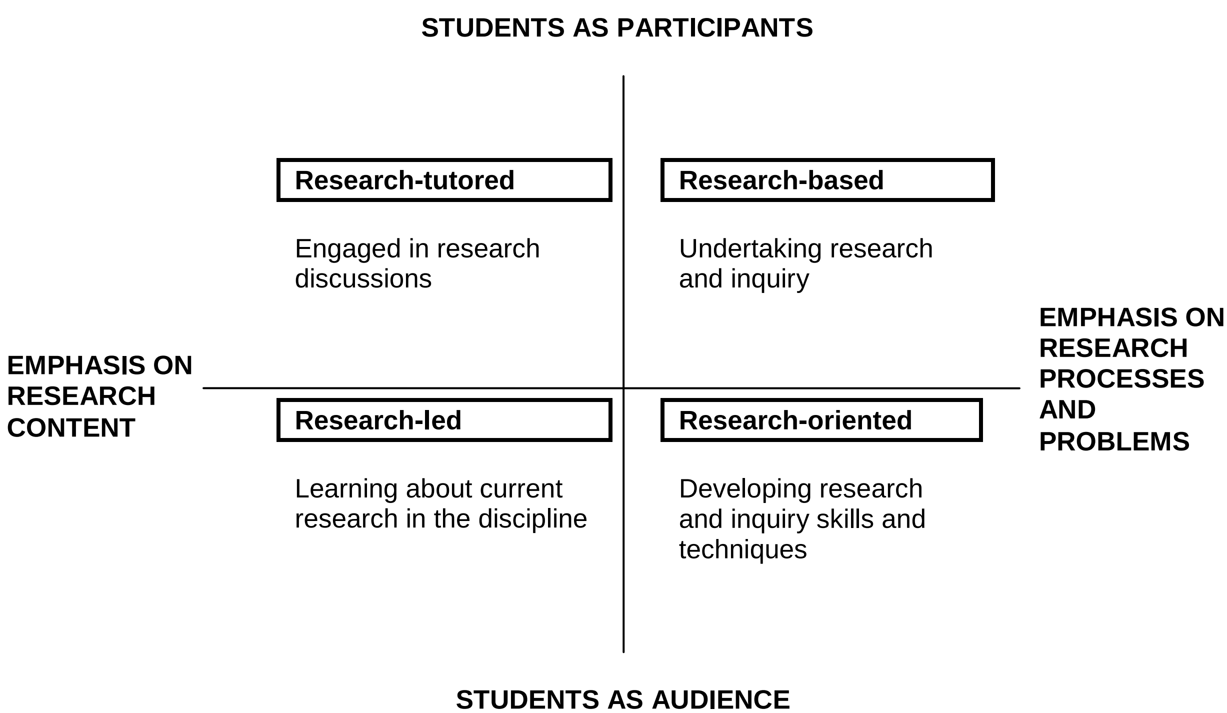
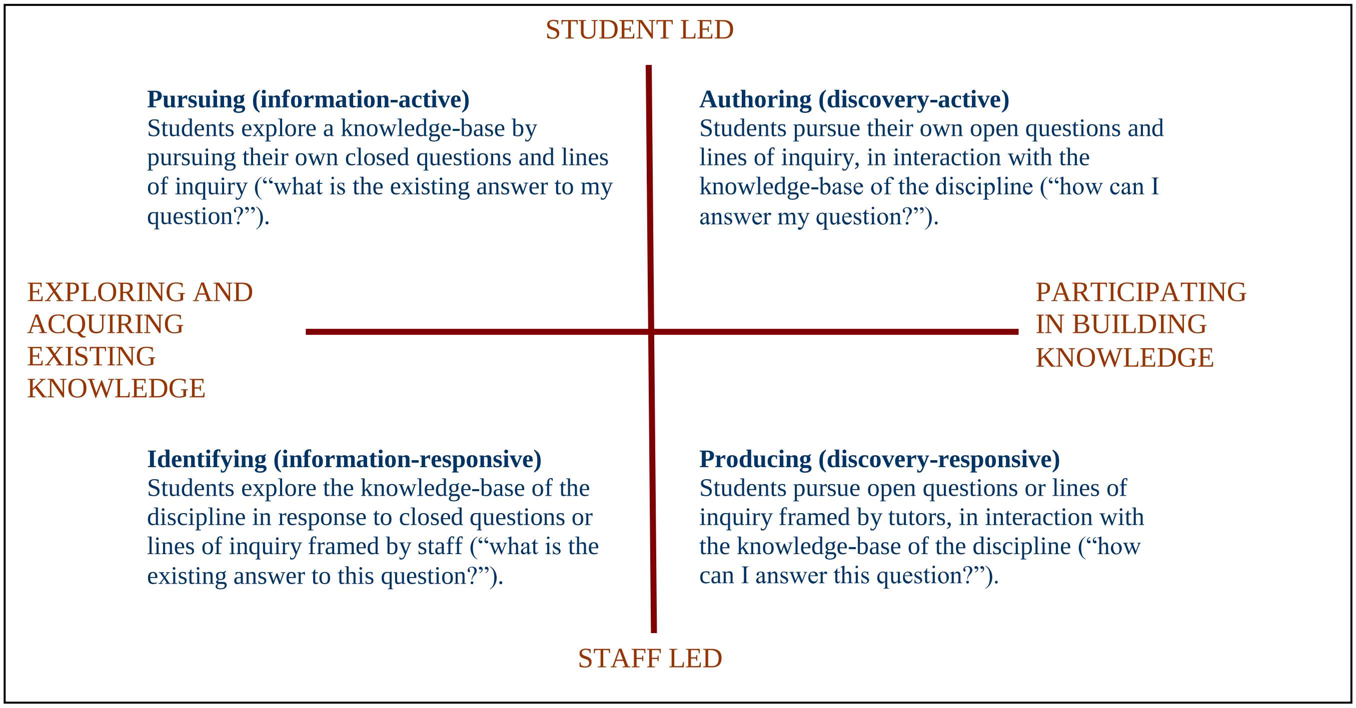
The material in this handout has been developed over several years with Alan Jenkins, Professor Emeritus, Oxford Brookes University, UK; alanjenkins@brookes.ac.uk. Further and more detailed case studies, including institutional and national examples, references and a list of useful web sites may be found at: www.mickhealey.co.uk/resources. Several of the following case studies are taken from Healey and Jenkins (2009) and Healey *et al*. (2013) some of which have been updated.

Fig 1 Curriculum design and the research-teaching nexus



Source: Healey and Jenkins (2009, 7), based on Healey (2005, 70)

Fig 2 Inquiry-based learning: a conceptual framework



Based on Levy (2009)

A. Engaging students in research and inquiry at the beginning of their academic studies

1.1 Introducing students to staff research: department of mechanical engineering, Imperial College, London, UK
This activity was a feature of the first year course in Mechanical Engineering at Imperial College London in the l990s. We lack firm details on some of the aspects of this activity. If anyone has them please contact us.

- In January of their first year mechanical engineering students were divided into 10-15 groups of 4-5 students
- Each student group was given an engineering 'artefact' e.g. a safety razor; the bottom frame of a bicycle. In the next few weeks these student groups could knock on the doors of any of the department's research groups or staff, and ask questions around the issue of 'what research are you doing that might effect how this artefact will look like and function in c5 years' time?'
- Later all student groups presented a poster which provided a summary of their findings
- The poster session was held in large public space in the department with some 700 attending; academic staff, support staff, postgraduates and first year and other students

Source: Correspondence with Erik Meyer who witnessed this as a visitor to the department

1.2 1,500 biology students are involved in research at University of Sydney, Australia
First year Biology students at the University of Sydney contribute to the understanding of the prevalence of asthma in Sydney. Each student learns to pour an agar plate which they take home and expose in their back yard over a 10-minute period, to collect a sample of airborne fungal spores in the atmosphere. There are 1000 students in the class and they live all over the Sydney metropolitan area. Once the fungi collected have grown into colonies, students learn to use a key to identify the fungi, and the class results are converted into maps showing the distribution of the different species. This generates new knowledge, which they discuss online with an international expert, and which is fed into research programs on allergens. The students involved reported a better awareness of research, and their involvement in it, than students involved in a practical course which had a traditional textbook demonstration practical exercise. Dr Charlotte Taylor describes a thousand students as an 'ideal' size of research team for carrying out research of this nature.
Sources: Taylor and Green (2007); http://www.mq.edu.au/ltc/altc/ug_research/research_curriculum.htm

1.3 Introducing students to academic staff research: Department of Geography, University College London (UCL)
All year one students in Geography at UCL do an assignment in term one, in which students interview a member of academic staff about their research.

- Each first-year tutorial group is allocated a member of academic staff who is not their tutor.
- Tutorial groups are given three representative pieces of writing by the member of staff along with a copy of their CV, and a date is arranged for the interview.
- Before the interview, students read these materials and develop an interview schedule.
- On the basis of their reading and the interview, each student individually writes a 1,500 word report on: a) the objectives of the interviewee's research; b) how that research relates to their earlier studies; and c) how the interviewee's research relates to his or her teaching, other interests and geography as a whole.

A variant on this entitled ‘Meet your Lecturer’ has been integrated into first year tutorials by other departments at UCL. For example, in Structural and Molecular Biology department students are given a tour of a research laboratory; in linguistics groups of first year students ‘meet a researcher’ in their first week; in another department the output of the meeting is that students make a short video about the Professor’s research.
Source: Dwyer (2001); https://www.ucl.ac.uk/teaching-learning/case-studies-news/connected-curriculum/meet-lecturer-personal-tutoring-difference; https://www.ucl.ac.uk/teaching-learning/case-studies-news/research-basedlearning/meet-researcher-linguistics

1.4 Design-centred inquiry-based learning opportunities for year 1 students embedded within the Integrated Engineering Programme (IEP) at University College London (UCL), UK
From the autumn of 2014, all first-year engineering and computer science students enrolled at UCL undertake independent research to inform, guide and inspire their project design brief, ideas and solutions during the first of two 5-week interdisciplinary ‘Challenges’. A principal objective of the IEP is to have students graduate from UCL Engineering skilled with the ability to take on a problem, navigate their way through a process of design, employ ‘engineering thinking’, and generate solutions that are efficacious for all stakeholders involved. The creative, yet iterative, process of design requires continuous questioning, investigation and resilience on the part of the student design teams. As the themes for the ill-defined problems of the two Challenges are steeped in such global challenges as sustainability and health, cultural and community, partners, as well as technical experts, were introduced as part of the teaching team or as external advisors to enrich the student experience. Such collaborations from across the university, within the UK and around the world open up exciting opportunities to embed authentic and enquiry-based learning into the design-centred curriculum of the IEP year 1 Challenges module. When asked to reflect on their team’s experience of using the design process to solve a problem, one student wrote:

> “Our initial step was to research into what the actual problem was. We investigated and researched further into the problem to find out about all aspects of the energy problem. We looked at all aspects of the problem, not just the technical bits, and then started to think about some good and viable solutions for the problem. The research helped us come up with ideas. The research was tough though, sometimes I had no idea what I was reading or what I asking the external advisors, but we had many study sessions together as a team and meetings to brainstorm ideas and then we started coming up with some real diverse solutions.”

Source: Correspondence with Emanuela Tilley (e.tilley@ucl.ac.uk); http://www.engineering.ucl.ac.uk/undergraduate-study/iep/

1.5 First year students pose questions through observation in biology at ANU, Canberra, Australia
In groups of 12–20 students, students conduct this exercise while walking through the nearby Australian National Botanic Gardens with a demonstrator (TA) as part of the 350-student introductory class on Evolution, Ecology and Genetics. The exercise takes 2 to 3 hours, plus some time to write up afterwards. It gives first year students the liberty to start thinking like scientists, to stimulate their curiosity and to get them talking to their peers. Students are taken for a short walk through the gardens and encouraged to observe their surroundings. They then are sent off ‘solo’ for ~30 minutes to write down 10 questions (e.g. Why do eucalyptus leaves dangle?). Each student then reads one or more of their questions to the group and together the students and tutor restate the question as a hypothesis (e.g. eucalypt trees in arid environments have leaves that dangle at steeper angles than those in wet environments) and design an experiment to test that hypothesis. The exercise builds confidence and comfort with the experimental

process, demonstrates what makes a 'good hypothesis', and begins to get students thinking about elements of experimental design.
Further information: Adrienne Nicotra (adrienne.nicotra@anu.edu.au);
http://biology.anu.edu.au/adrienne_nicotra/

1.6 Changing how first year students view experimental physics as a learning experience: The 'Secret Objective' at University College London, UK
One of the problems that 1st Year, undergraduate experimental physics courses have is the way that students approach the discipline. Often their previous experiences have been limited to directed demonstrations rather than experimentation. It is not unusual for students to view physics experiments to be a recipe that they follow to get a 'correct' answer. Indeed, some students have said that, in the past, they were quite happy to make up results so that they matched their expectations regarding the successful experimental outcome. This is not what we want physicists to do.

Consequently, a new teaching concept was introduced at University College London's 1st Year practical physics courses: The 'Secret Objective'. Students are encouraged to believe that not all of the scripted experiments were as straightforward as they seem. Doubt is placed in the minds of the students about the validity of their preconceptions regarding the outcomes of experiments. They are told that some experiments have been modified so that they will not behave as expected. This can range from the theory in the script not being sufficient to explain the data, to anomalies in the experimental system that cause interesting problems. Indeed, some experiments can have multiple Secret Objectives. Therefore, the students are trained to look for anomalies in the practicals that might have been placed there by the experiment creator. Breakout sessions are used to discuss what they think the 'Secret Objective' was so that a discussion can take place regarding how career physicists approach experimental challenges and unexpected findings.

Consequently, they actually analyse their experiments rather than purely copying values in their laboratory notebooks without any critical thought. They actively observe in a way that is quite new to them. Indeed, they often find Secret Objectives that are not placed there by the experiment creator but are there as a result of the real physics. That is what we need them to do and 'Secret Objectives' are a means to do this. It is habit forming.
Further information: Paul Bartlett (paul.bartlett@ucl.ac.uk)

1.7 Year one concentrated activities in mechanical and automotive engineering, civil engineering and computing at Coventry University, UK
These three programmes start with intensive c6 weeks of guided activities. In mechanical engineering there are six week long activities all of which include 2 or 3 hours of key note presentations, 14 or 15 hours of facilitated activity and 1 hour of assessment. Each week students are given their mark and feedback before departing for the weekend. In civil engineering, year 1 students start realistic group project work in the first weeks of their course. In recent years topics have included a footbridge in a park, and a cycleway connecting tourist attractions. The project is revisited later in the year for an intensive one-week activity culminating in presentations to an audience of local employers. Integrated project work runs through the three year programme. The final year integrating project includes all students of the Department working in multi-disciplinary teams (civil engineers, building services engineers, construction managers, architectural technologists, building surveyors and quantity surveyors) working on a real brief, supported by inputs from practitioners. In computing, in their first six weeks students undertake a set of week-long tasks that build into a single project-for example to develop an MP3 player.
Source: http://www.coventry.ac.uk/research/research-directory/higher-education/activity-led-learning/activity-led-learning-case-studies/

1.8 Scientific Communications 101: A student organised science conference at Curtin University, Australia
Students in an introductory year one course with a linked focus on physics and science communication were required to plan and present a one-day Physics conference. The context was an institutional requirement that employment focused communication skills be integrated into disciplinary programmes. The idea of a student-organised science conference, publication of the proceedings, and the reasons for the approach were explained to students in the first

Physics class. For the following week, students were asked to decide on a Physics topic they were interested in presenting at the conference, the overall theme for the conference, and how all the students would contribute to the organisation of the conference and the publication. Later in the term the conference took place over a day and staff and students from the department and local high school students and their teachers attended. In the years that the course ran it succeeded in helping students develop more effective communication skills linked to their discipline, introduced them to research debates and helped them begin to think and communicate like physicists.
Source: Zadnick and Radloff (1995)

1.9 *Terrascope*: First year geoscience and engineering students investigate a complex problem at Massachusetts Institute of Technology (MIT), US
Terrascope is a cross departmental optional programme for year one students. Each year addresses a different theme, for example, tackling global climate change by removing carbon from the atmosphere. The pedagogy is 'problem based learning' with a minimum of structure, but with a range of support from faculty, librarians, upper-level students and alumni mentors.

In semester one, students form themselves into groups of 5-10 and develop their understanding of possible solutions to the chosen issue. Each team has to "produce a comprehensive web site that outlines the problem and how they propose to solve it" (Bowring *et al*., 2014). In the second semester the main offering is a class where students are presented with a range of research questions relating to that year's theme and investigate these in teams. Each team has to produce a booth filled with resources which demonstrate their research topic. These are then presented at a public 'Bazaar of Ideas', where members of the public and faculty question the students. The other semester two option 'Terrascope Radio' focuses on public dissemination of student work on the theme. Each group produce a programme which is broadcast on MIT radio. Terrascope students can also choose to join an annual spring field course, often in an international venue, on that year's theme. Entry to the programme is effectively by student choice and each year some 100 students enrol but "it is not uncommon to lose a third by the end of the third week. Students who continue become deeply engaged in the class" and produce high level work (Bowring *et al*., 2014).
Source: http://web.mit.edu/terrascope/www/; Bowring *et al*. (2012)

1.10 First year design through problem-based learning in Mechanical Engineering at University of Strathclyde, UK
Students are aware that they will undertake a 'Mechanical Dissection' of a car before enrolling at university: the exercise is highlighted in the degree prospectus and open days. At the beginning of the first year, the structure of this class is explained to the students so that they know when in the year they will be working on the car dissection. It is also emphasised that the tasks they must undertake are related to the development of research skills for later in their Course. Each student group spends a couple of hours selecting a part of the car (for example the front or rear suspension, or a part of the braking system) and removing that part. The following day each group meets with two lecturers to discuss the physical principles behind the component's function, and to select a couple of parts for further examination. These parts are examined under the microscope to ascertain the materials and processes involved in their manufacture. The students then have (in the style of Problem-Based Learning) to research the functions, physics, manufacture and design of the components, and to produce a poster explaining these. They present their draft poster to two members of staff, who discuss the content with them and inform the students of any further work necessary to bring the poster to an acceptable standard. The students then have to produce a brief PowerPoint presentation covering the same material as the poster for a conference plenary session at which two students, chosen at random, from each group describe their component to the rest of the cohort. After their presentation, each group has to field a couple of questions from one of the other groups of students. In preparing the poster and presentation students will need to explain topics not covered elsewhere in their first-year course. The overall aim in developing this class was to show the students how the rather theoretical academic work they cover in their lectures is relevant to the practical challenges of engineering. The tasks associated with producing the poster and presentation also build skills in team work, research skills and communication and encourages independent learning. The students said this exercise 'is probably the only thing that everyone spends the whole first year waiting for', it 'expands on so many skills', and that it 'allows you to see how an engineer would think'.
Source: Land (2013)

B. Final year and capstone projects

2.1 Integrating professional and technical competencies in a final year engineering capstone design course at the University of New South Wales, Australia

In this final year capstone design course which last ran in 2009-10 the pedagogy was centred on the 'student as engineering design consultant', utilising authentic learning experiences obtained through collaboration with industry who contributed a variety of commercial design problems for student design teams to work on. In the course, students were allowed to form teams and choose from six industry-provided design problems that were outlined to the students in a one day presentation by key employees of the five companies involved in the course. The course had only six lectures over the entire 12 weeks of the course with learning activities aligned to support the design projects. The course aims were to achieve a balanced set of outcomes, integrating knowledge and skills from both technical and professional competencies. Emphasis was placed on making explicit the process of identity change from a student to a professional engineer.

2.2 The Mechanical Engineering Final Year Project at University of Adelaide, Australia

The final year project in the School of Mechanical Engineering aims to provide solutions to engineering problems related to industry or to scientific research, with emphasis on project management and effective communication. It is considered to be an important part of the engineering education process and projects sponsored by local industry are strongly encouraged. Industry sponsored projects enhance student skills through relevant real-world projects in research and development, and profits industry by collaboration in training expertise transfer, innovation, and development. Students work in teams ranging in size from one to a dozen. Although the projects require a minimum of 330 hours of student time, many students spend over 600 hours and some up to 1000. The scope of the projects is often ambitious, such as the design, build and launch of a supersonic combustion RAM jet, or a Formula SAE racing car. Students are encouraged to suggest projects themselves as these often lead to outstanding outcomes. The projects are facilitated by the extensive resources put in place by the School to support the students including the provision of a project budget and access to workshop staff time and manufacturing facilities. Each project has at least one academic supervisor, and in the case of industry sponsored projects, an industry-based supervisor.

2.3 Alternative Final Year projects in the Biosciences at the University of Leeds, UK

Final year students within the Biomedical Sciences group of programmes (Human Physiology, Medical Sciences, Neuroscience, Pharmacology) have the opportunity to undertake one of the twelve types of research project. Each project is of 8-weeks duration, with students expected to commit 3.5 days per week to their project. Students are provided with a list of projects (with project descriptors) in March of the year preceding their final year and invited to choose, in rank order, 10 projects they would like to be considered for. Projects are then allocated based on student choice and ranking within the year group; with projects staring in the January of their Final Year.

The assessments for all project types are similar. Students are required to write a 25-30 page dissertation and deliver an oral presentation. Students undertaking critical review projects also have to submit a 5-page grant proposal linked to their review. There is also a supervisor allocated "productivity" mark.

i. *Individual laboratory projects*

   Students undertake an individual programme of research in the laboratory of their project supervisor, often contributing to ongoing research within that laboratory.

ii. *Group laboratory projects*

   Students work collaboratively, in a team of 3-4, to undertake a programme of research, based either in their supervisor's laboratory or in the teaching laboratories. The format of the project varies between groups; they could all be undertaking similar studies or addressing different elements of a research question (e.g. using different techniques or pharmacological agents). The design of the studies and ongoing development of the project is decided collectively by the group. At the end of the programme of research, all data is shared, but each member of the group writes their dissertation and delivers their oral communication independently.

iii. *Computer simulation projects*

   Students investigate the function of biological systems using established computer models (e.g. human cardiac myocytes). Students are trained in the use of these models (e.g. to obtain and plot ionic currents, action potentials, action potential durations etc). They then challenge these models.

iv. *Bioinformatics (plus) projects*
Students undertake data-mining exercises of publically available databases (e.g. to identify candidate gene sequences); the area of interest decided in consultation with their supervisor. The information gained will then be utilised in subsequent laboratory studies undertaken by the student (e.g. transfection of DNA into cells; human physiological studies).

v. *Critical review projects (with linked grant proposal)*
Students undertake a hypothesis driven critical review of the literature in a specific area/topic within the biosciences. They agree a research area/topic with their supervisor, construct a hypothesis and then search, evaluate and critically review the literature in this area to provide key arguments and evidence, both in support of and against their hypothesis. They then write a dissertation and a 5 page, self-contained, fully-costed grant proposal for a 1-year pilot study which, if undertaken, would advance scientific knowledge in one area of the research they reviewed.

vi. *Therapeutic or scientific audits*
Students undertake a meta-analysis of published data e.g. clinical trials, scientific techniques or protocols. For therapeutic audits, they will undertake a meta-analysis of published clinical trials to investigate the effectiveness of different therapies in an area of their choosing (e.g. effectiveness of pharmacotherapies versus lifestyle interventions versus bariatric surgery in the treatment of obesity). Statistical analysis is undertaken using open access software available on the Cochrane Collection website. They then use publicly available databases to expand their study and put the results into a wider context (e.g. post-code lottery prescribing, cost-effectiveness of treatments, prescribing patterns in different countries). Scientific audits are an evaluation of scientific techniques or protocols in a particular field e.g. the impact of husbandry and housing on preclinical research data obtained from laboratory animals

vii. *Survey projects*
Students undertake a survey of the public's attitude to a topical biosciences or health-related issue. In consultation with their supervisor, they decide their research question and client population (e.g. Evaluation of Fit-Fans, a lifestyle/health promotion programme for male rugby league supporters, attitudes to the use of legal highs or whether laboratory animals should be used in undergraduate education). They then design a questionnaire, evaluate its effectiveness through focus groups before using it to survey their client population(s) by conducting semi-structured face-to-face interviews. Students are required to compare a minimum of at least two populations or client sub-groups. On completion of the survey, they may put their results into a wider context by undertaking an extended, face-to-face interview with a key stakeholder (e.g. Head of the Primary Care Trust for the above Fit-Fans intervention) or look at environmental or other factors.

viii. *Science and Society projects*
Students create, deliver (up to 13 times) and evaluate an interactive, curriculum enhancing teaching in local primary (students aged 7-11) or secondary (students aged 13-18) schools. Students design a teaching session on their allocated topic. It must be interactive (i.e. not a didactic lecture) and curriculum enhancing (i.e. be part of the national curriculum), but something the teachers themselves can't deliver (e.g. though lack of equipment, recent advances in science etc). The session must be modifiable for different year groups or session lengths. It must also incorporate a means of evaluating student knowledge acquisition, and feedback from both students and staff.

ix. *Science communication and Public engagement projects*
Students create, disseminate and evaluate resources to engage different with complex science e.g. infographic's or animations to inform on the science behind a commercial company's products or patient information leaflets to promote statin use. In consultation with their supervisor, they decide the target audience, ascertain the provider's (company, GP etc) public engagement needs or objectives, identify the most appropriate means or resource to communicate this information, create this resource and engage their target population with it, evaluating its effectiveness.

x. *Educational development projects*
Students create and evaluate learning resources for use in undergraduate teaching. Working either individually or in small teams, students develop learning resources or new teaching methods (e.g. social media) to support ongoing teaching. The resources developed address needs identified by their supervisor (e.g. challenging topics). Students decide the most appropriate format (e.g. online data analysis tutorial, multimedia presentations, wiki).

The resources are then implemented into the curriculum and the students evaluate their suitability and effectiveness using surveys, focus groups and interviews.

xi. *Digital resources projects*

This is an extension/modification of educational development projects. Students will create an interactive digital learning resource for use in undergraduate teaching using the open source, e-learning software Xerte. The topic of the resource and the interactive content (e.g. videos, web-links, quizzes etc.) to be decided in consultation with their supervisor. Given the time constraints of the project, it is unlikely that students will be able to implement the resource they have created into the curriculum and therefore evaluation of its quality and effectiveness will be provided by focus groups.

xii. Commercial projects

Students will write a technical, market research or business report for an identified business client (e.g. market research on their/their competitor's products; evaluation of the impact of new legislation).

All of the above project formats can either be individual or team-based projects. The latter have grown in popularity (e.g. 60-70% of the lab projects are now group based and most ask for the non-traditional ones, to be run as a group). Data is collected by the group and students sort out an equitable allocation of work themselves. However, assessment, both the written dissertation and the oral presentation, is individual.
Further information: http://curriculum.leeds.ac.uk/rbl/final-year-project or email d.i.lewis@leeds.ac.uk

2.4 Chemistry 'Concentrated Study' Project at the University of St Andrews, Scotland

This is a core course done by all 3rd year chemistry students (within a 4 year BSc/5year MChem framework); current enrolment is 48. It is taught in the last four weeks of the Spring semester. Students have no other class and are able to spend their full time on this module. Students are divided into (mixed ability) groups of five - six each assigned to an academic supervisor who assigns a topic for investigation. This requires some literature research, experimental planning, experimental work, analysis of results and their presentation. The projects assigned vary but generally fall somewhat short of original research while maintaining substantial scope for student input to the direction of the work and how to best achieve the goal set. The module has run for the last five years and typically yields grades rather similar to conventional laboratory classes at this level. A consistent observation however is that this really brings out the best in some otherwise weaker students who seem to be inspired by the idea of contributing to the team effort in a way that is not achieved in a more conventional class. It provides a sound preparation for those students who go on to take an honours project.

2.5 Across department undergraduate research programme in College of Engineering, Maryland, USA

Gemstone is a highly innovative programme for selected 'honors' students in engineering and other disciplines. The programme is now in its seventeenth year. Student teams, formed in the freshman year, undertake three-year, student-initiated research projects in which they analyze and propose solutions to societal problems, which generally involve a significant technology focus. Team members work as a coordinated group, investigating their project from the perspective of individual majors, under the guidance of a faculty mentor. In their first two years students are encouraged to live together on a residence hall floor reserved for Gemstone participants. The research projects e.g. 'a comparative study of erosion control measures in the Chesapeake Bay area and homeowner response to such interventions', are developed in consultation with outside experts and agencies. In their final year student teams present their research to experts in the field or outside agencies and write a team thesis. The learning process mirrors the team based consultancy style research that students are likely to carry out after graduating. The students present and defend their team research at the Team Thesis Conference. The presentations are 30 minutes long followed by 30 minutes of questions from the discussants and the audience. Following this the team have one hour in a private discussion room with their discussants and mentor for feedback on the presentation and thesis.
Sources: http://www.gemstone.umd.edu/; http://www.reinventioncenter.miami.edu/spotlight.html;

2.6 GEOverse: A national journal for undergraduate research in Geography at Oxford Brookes and three other universities, UK

GEOverse is a national undergraduate research journal for Geography which has been piloted in four institutions. The geography departments in Oxford Brookes University (the lead institution) Queen Mary, University of London, the

University of Gloucestershire, and University of Reading comprise the editorial board of the journal. GEOverse publishes student-led original research based on theoretically considered and empirically-based investigations undertaken at undergraduate level. The aim is to motivate and reward students for producing innovative and best undergraduate research practice, and then give them support through the review process before disseminating their work through publication. Papers are reviewed by a panel of postgraduate students.

Students at Oxford Brookes undertake a compulsory second year module called *Geography in the Field* where they go on a field trip and work in groups and collect data. An optional third year honours module was created in which students could write up their research as a paper with supervisory support from a tutor. This resulted in many students becoming authors of research papers but in a supervised manner. This helps fill a gap in the research cycle for undergraduate students because they did not get the same kind of constructive, meaningful and useful feedback that an academic would get from going to conferences, putting papers in, and getting feedback from peer reviewers. In this module students get dialogic feed-forward on their work and they are provided with an opportunity to disseminate their research through organizing a set of undergraduate conferences as well as the opportunity to publish in GEOVerse.

The work has also impacted on the work of colleagues in other institutions and transformed their curricula. Colleagues at the University of Reading have replaced an examination with writing a journal article for GEOVerse. The University of Gloucestershire has developed a collaborative writing assignment in which students write a collaborative journal article. At Queen Mary, University of London they have an expedition to Iceland. Students are given the opportunity to produce a research paper on their return.

2.7 Final year students undertake team research projects on local environmental issues at the University of Gloucestershire, UK

Issues in Environmental Geography ran for about a decade at the University as a final year capstone module; and an earlier version ran at Coventry University for several years. Students worked in groups of 4-6 on local environmental issues. The module was concerned with analysing competing environmental philosophies, applying them to understanding a particular local or regional environmental issue and coming up with policy recommendations. The students developed their own projects, starting with a proposal. They were supported through two key lectures on environmental philosophies, a workshop on effective teamwork and individual group tutorials on their chosen topics. The semester long course was assessed through a group report (60%); oral presentation of project (30%) and an individual learning journal and reflective essay (together counting for 10%). The marks given for the group project were redistributed among group members using peer and self-assessment of the quality and effectiveness of their contributions on a five point scale to five group processes (ideas and suggestions; leadership, group organisation and support, minute taking; data collection/ collation/ analysis; report writing, production and editing; and preparing/ giving verbal presentation). The average mark for the module was consistently c3-5 percentage points higher than for other modules reflecting the benefits of working in teams. The difference in marks was confirmed by the external examiners.

2.8 Collaborative and Student-driven Learning Approaches to Capstone units in ICT at Macquarie University, Australia

The *Systems Engineering Project* was designed to create alliances between top computing students, academics and industry to the benefit of each party. Student groups are engaged in a variety of research and development projects, including; investigating for themselves how the company works, what the problem really is, what are the range of solutions, how does this technology work and so on, and writing these up. To ensure that each team member gains the most from the experience, the roles within our teams are rotated; significantly everyone must have a turn at being the project leader. Decisions made regarding the various design and management choices must be justified and be based on the environment they are working within: thereby providing students with greater autonomy and ownership of the project.

2.9 Facilitating Student Professional Readiness through Industry Sponsored Senior Capstone Projects at Western Carolina University, USA

The Kimmel School's Department of Engineering and Technology at Western Carolina University (WCU) has implemented a 5-course engineering project based learning (PBL) core culminating in a senior capstone course sequence, focused on new product/process development. The department has partnered with The Centre for Rapid Product Realisation in delivering and administering the PBL and capstone courses. Both equipment and staff are being shared in a collaborative effort to meet the needs of both industry and students. The capstone projects vary across several areas including medical devices and testing equipment, manufacturing products and processes, military and tactical devices, solar collectors and control devices, and sports equipment redesign. The joint collaborative partnership has produced well over 100 industry related products/processes with several resulting in application for patent. The *CATME* Team-Maker is employed in the development of student teams and the assignment of projects. Faculty and industry mentors are assigned to each team at the beginning of the course sequence. As a first step, project management techniques, such as work breakdown structures, Gantt charting, scheduling and quantitative trade off studies, are presented to the students. The stage-gate process is employed as a means of monitoring the progress of student teams. As a second step, faculty mentors work closely with each team during the design, build, and test stage-gates. A variety of presentation methods are used by the students in disseminating their progress at each gate. Several methods are used in assessing and characterising student progress and performance including the CATME, instructor assessment, faculty mentor assessment, and industry-customer assessment. Overall, the collaborative partnership has been a positive experience for all collaborators and student learning has increased significantly. Several problems with our model have arisen, including: equitable evaluation of projects that vary in scale and complexity, managing unequal team member contribution, student time-management issues, and faculty loading.

2.10 Communicating Maths at the University of Bath, UK

Communicating Maths is an optional module for third and fourth-year students in the department of mathematics. The project aims to provide mathematics students, who are traditionally poor communicators, with the opportunity to demonstrate competency with these skills and to evaluate their ability, whilst increasing student interest in teaching careers and provide ambassadors of mathematics and the University of Bath within the wider community. The students involved undertake a wide range of activities designed to enhance and broaden the public understanding of mathematics, with a particular emphasis on working with local schools. All of the students on the course attend training and over the course of one semester undertake four tasks:

1. 'Bath Taps into Science', a science fair based in Bath during National Science Week. Undergraduates work in teams of four, running a half day exhibition on a subject of their choice which they have researched.
2. Mathematics master class for school pupils aged around 13 led by the students.
3. The third task is drawn from a number of different options. This can vary from students choosing to deliver a lesson in a local primary or secondary school (working with a local teacher), to working with Maths Inspiration, Dr Maths, or with the Further Maths Network.
4. Research and produce a permanent piece of work on a mathematical topic of their choice. Various mediums have been used including posters, web-sites, a YouTube video, and newspaper articles

2.11 Bioscience End of Year Project at Durham University, UK

Bioscience students at Durham University have a choice of three different types of final year project

(a) Laboratory-based project

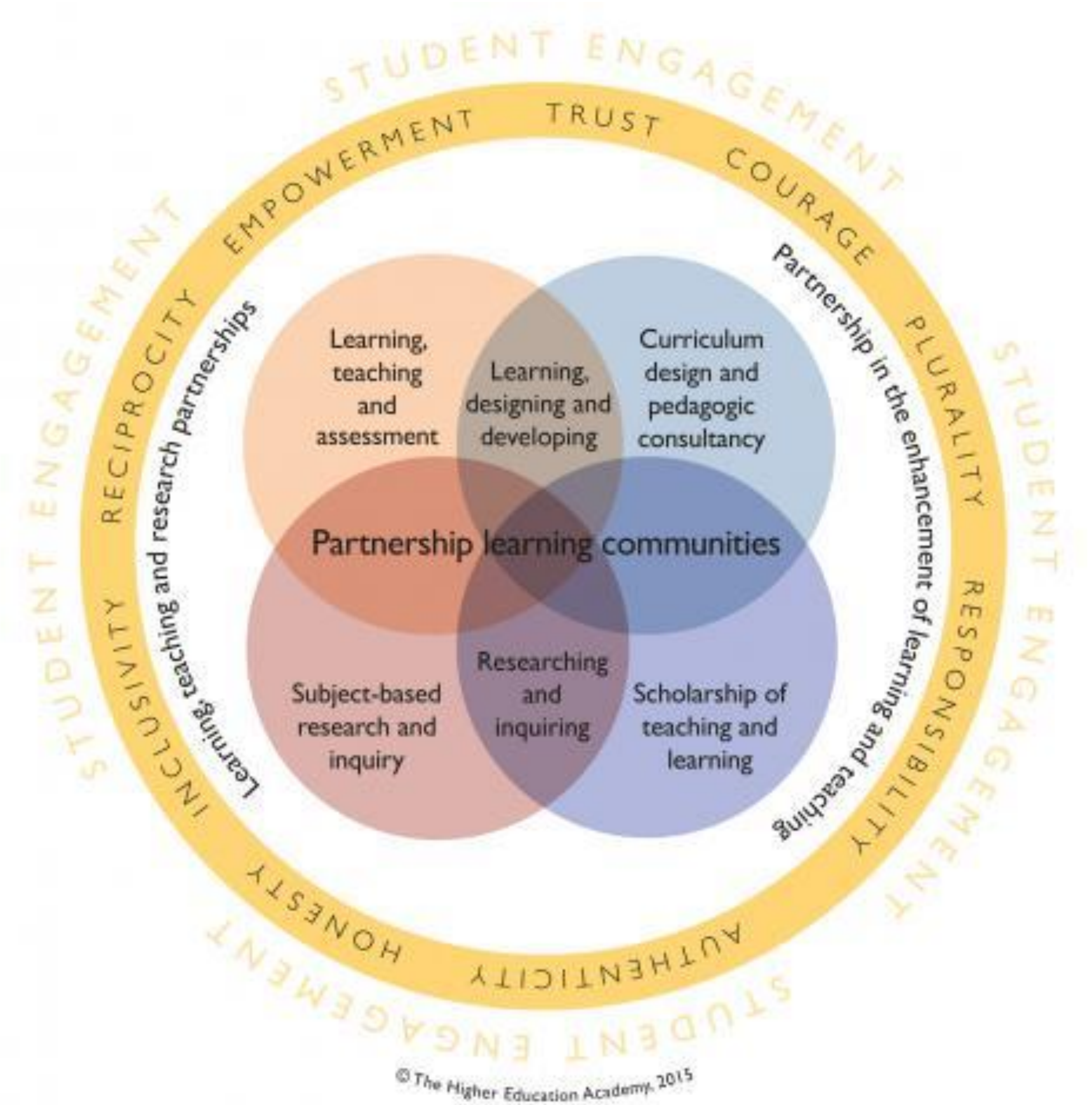
The laboratory-based project provides an opportunity to participate in the research being carried out by staff in the School. Many students are able to work in the research laboratories, alongside postgraduate and postdoctoral researchers, and all students have access to the full array of research facilities in the School. The project currently takes place over 5 weeks of full time research, and students are given a piece of work that can lead to concrete results in this period. Many undergraduate projects have generated data that has subsequently been incorporated into scientific papers, with the student as a named author. The project is assessed through a report, written in the form of a mini-thesis, and a short presentation. This module gives the student a taste of scientific research, and exemplifies the School's commitment to providing research-led education.

(b) Biology Enterprise
Biology Enterprise (BE) is project-orientated module, based on research in a commercial context, with self-selecting groups of 5 or 6 students working together. The learning context for BE follows the real-life scenario of the formation of a biotechnology spin-out company from an academic biosciences research group. Within this context BE aims to introduce students to: key processes of business start-up, specifically in the context of a spin-out of an innovation generated as a result of biological research; key factors and considerations that influence the decision making process of the commercialisation of biotechnological innovation; the necessary skills, knowledge and resources required to take biological innovation from concept through to credible commercial propositions; the purpose of a Business Plan and, using a self-generated idea, how to prepare and present a Plan for a research-led biotechnology spin-out. A core component of BE is an in-depth desk study of a biological topic to collate, review, critically appraise and present the scientific research evidence that underpins the self-generated idea for the biotechnological product or process. The content of this module provides an introduction to key business processes such as ideas generation; market research; protection of intellectual property; raising finance, in addition to developing individuals' team working, project planning, time management and transferrable skills
(c) Biology into Schools
For students who see their future in science education, or other communication-based activities such as journalism, the Science into Schools module may provide an attractive option. As for the other research project options, it is research-led, but in this case the research takes the form of a systematic inquiry into the teaching and learning process. Students are required to prepare materials for teaching science in secondary schools, and to interact with teachers and pupils. After an initial training period, students spend at least 4h per week for 10 weeks in a local school. They are expected to graduate from classroom observation, to assistance in teaching, to an opportunity to undertake whole class teaching. They will also devise a special Biological Sciences project for the school, which they implement and assess. The module is assessed through a journal of activities, reports, a presentation, and a report by the host teacher. This module is focussed towards developing communication skills, as well as team working and interpersonal skills. This module is only available to a limited number of students, determined by participating schools.

2. 12 Students in Engineering, Computer and Mathematical Sciences present their project findings to industry, public, schools and university at the Ingenuity Fair, Adelaide, Australia
Ingenuity is the annual flagship event for the Faculty of Engineering, Computing and Mathematical Sciences at the University of Adelaide. It serves as a valuable platform for students to professionally present their work to a wide range of specialist and non-specialist audiences, including university peers and staff, industry representatives and recruiters, primary and high school students and teachers, family and friends, politicians and members of the general public.

In 2016, 280 student capstone projects from over 660 student exhibitors were on display at the Adelaide Convention Centre. Over 4,500 people attended. The showcase took place on one day at the end of the academic year with the previous evening reserved for industry visitors. The exhibition was organised around nine cross-disciplinary themes – defence and security; energy; health; innovation and research; resources; smart systems and technologies; society and environment; structure and infrastructure; and sustainability.
Source: http://www.ecms.adelaide.edu.au/ingenuity/; correspondence with Bernadette Foley

Fig 3 Students as partners in learning and teaching in higher education: An overview model



Source: HE Academy (2015) Based on: Healey, M., Flint, A. and Harrington, K. (2014) *Engagement through partnership: students as partners in learning and teaching in higher education*. York: HE Academy p.25.

The model is discussed in:

Healey, M., Flint, A. and Harrington, K. (2016) Students as partners: Reflections on a conceptual model, *Teaching and Learning Inquiry* 4(2)