The Design of an Innovative Research Led, Undergraduate Programme for Effective Development of R&D Skills and Learning.

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Abstract

Engineering education has suffered a shift in focus between research led fundamental engineering and vocational training that has resulted in many graduate engineers equipped without a thorough grasp of either skill set. Furthermore the belief that these two components of education can be explicitly separated appears to undermine the notion of what a graduate engineer is. The purpose of this paper is to outline the development of a research informed, undergraduate, module that incorporates the principles of the Massachusetts Institute of Technology developed approach to engineering education where the core components of study are formed around the concept of CDIO (Conceive, Design, Implement, Operate). We outline our initial starting concept for the taught module and systematically break down the CDIO approach, applying the outcomes of this process to the design of the engineering module. The resultant module structure incorporates the majority of the CDIO principles, and highlights the mechanisms by which research can inform undergraduate teaching without straying away from the development of practical skills required by the graduate engineer. This work suggests that the CDIO approach, with minor modification, can be tailored to a single isolated module structure as well as a whole curriculum provided that there is a clear objective outlined at the start.

1. Introduction

Engineering has long been taught as an undergraduate subject across a wide range of institutions, each with their own specialism within the field. In many cases these institutional specialisms are the result of new emerging industries. In turn this leads to the development of taught courses aiming to equip graduates with the necessary specific skills required for these up-and-coming industry sectors.

In many cases the incremental development of a degree course can result in fragmentation or broadening of the taught material becoming disassociated from the practice of engineering (Crawley, 2002) in part due to time constraints but also due to a change in focus towards research. This change is considered to result in students having a detailed top level approach to simple engineering problems, but lacking a thorough understanding of the underlying principles required to resolve more complex issues. Research conducted by both Jenkins (2000) and McNay (1999) suggests there is further fragmentation between the research and teaching aspects in higher education.

As a result of this apparent increasing fragmentation associated with engineering education, researchers at the Massachusetts Institute of Technology identified and codified a set of goals for engineering education. These goals were developed with the intention of providing a basis for curricular improvement and outcome based assessment, the result being *“The CDIO Syllabus: A Statement of Goals for Undergraduate Engineering Education”* (Crawley, 2001; Crawley, 2007).

CDIO (Conceive, Design, Implement, Operate) aims to provide the necessary structure to create a rational and complete set of goals that are considered to be both universal and capable of general application. Specifically the system focuses on personal, interpersonal and system building skills with complimentary structural placeholders to allow for the inclusion of any discipline specific subject knowledge that may be required.

Fundamentally the CDIO initiative aims to address the growing tension between the two primary factors governing undergraduate education – that of ever increasing subject specific technical knowledge and the wide array of personal, interpersonal and system building knowledge required of a young engineer in a real world environment.

The focus of this paper centres on recent developments at the University of Hertfordshire (UoH). This University offers a number of engineering courses across a variety of disciplines including aerospace, mechanical, electrical and design engineering. To compliment the undergraduate and postgraduate taught courses there is also the opportunity to further specialise within a number of applied research groups, each covering a more specific subset of the engineering field. The Microfluidic and

Microengineering Research Group (MMRG) is one of these groups. Consisting of five post doctoral researchers from five separate engineering disciplines the MMRG, spearheaded by Professor of Microtechnology Mark Tracey, research and develop novel microfluidic solutions for the biochemical and microfluidic industries. The multidisciplinary, integrated nature of this group is considered atypical, whereby most other research groups have a more homogenous focus. It is this distinction that will be examined to determine whether the MMRG group structure can be embodied in a taught module and whether this lends itself well to the principles of the CDIO syllabus. The MMRG developed Microengineering and Microtechnology final year undergraduate module will be a test case for the approach. In addition while research focus has been attributed by Crawley as one of the possible reasons for the decline in engineering capability of undergraduate students (Crawley, 2002), it is the long established view, as echoed by Humboldt (1810, translated 1970) that Universities should treat teaching as a subset of research itself, whereby "learning always consists of not yet wholly solved problems", including researchers in the teaching programme clearly lends an added skill set to the learning programme.

2. Aim

The objective statement derived during the development of MIT's CDIO approach is particularly true for the emerging field of microfluidics and microtechnology whereby the assumption is that students should be able to:

> *"Conceive, design, implement & operate complex value-added engineering systems in a modern team-based environment"*

With the expectation that Universities should, where possible, review and refine their undergraduate offerings on a continuous basis the aim of this study is to investigate whether the application of the concepts embodied by the CDIO approach can be applied to the development of a new, research informed, undergraduate module targeted at the final year engineering student at the UoH. To add further complexity the module will reflect the interdisciplinary nature of a real world engineering department and as such will be offered across two dissimilar engineering disciplines (Mechanical and Electrical Engineering).The result of this process will be the development, delivery and support of the taught module Microengineering & Microtechnology (MTech).

3. Background

While it is often true that first year undergraduate engineering students share common components of study, generally the expectation is that the teaching becomes more subject specific and promotes enhanced specialism with each successive year. While this mode of academic study may develop graduates that reflect the needs of larger industrial organisations, where large departments of specialism may be found, it can result in skills gaps for the graduate employee of smaller, high tech start-up industries of which the Biotech industry is a prime example.

As a result of this potential skills gap a new multidisciplinary module was proposed. The aim in this instance was to incorporate the various specialisms of an already well established diverse research group into the undergraduate engineering syllabus. The module developed would be proposed as an elective module for both mechanical and electrical cohorts with the respective alternative modules: Manufacturing strategy and Telecommunication Systems. An initial framework for this module was developed centring on a number of principles of good practice as outline by Chickering and Gamson (1987) and incorporating the expectations of the UK Professional Standards Framework (The Higher Education Academy, 2006). In particular the interactions between student and faculty was considered to be a primary focus and thus the module was constructed around a backbone consisting of a group project case study, centred on one of the internationally recognised research outputs of the MMRG (Johnson et al. 2005). In small groups with dedicated, interconnected, roles the initial aim of the proposed structure was to encourage reciprocity and cooperation, a view enhanced by the opinion of Springer et al (Springer, 1999) who report that the implementation of various different methods of small-group learning are effective in promoting greater academic achievement, more favourable attitudes toward learning, and increased persistence in particular in relation to science, mathematics, engineering and technology. Furthermore by providing access to the entire MMRG research team it was anticipated that further interaction between the students and the faculty could be achieved. Lecture sequencing was designed to allow flexibility and remove potential barriers to success. A single point of contact, the Module Lead, oversees the delivery of the programme ensuring coherence in the structure and message conveyed by staff.

Another fundamental principle of the proposed module structure was to communicate a high expectation; thus students would be tasked with developing a variant of a device that was itself developed by a team of post-doctoral researchers, the challenge in this instance being one of pitching the objective appropriately such that it wouldn't become too daunting or onerous a task while maintaining the ethos of a cutting edge development. Additionally the initial scene setting for the module centres on an analysis of two seminal works within the field, that of Nobel Laureate Richard Feynman (Feynman, 1992) and Stanford Professor George Whitesides (Xia, 1998).

It was anticipated that the module would naturally incorporate a wide range of teaching styles and learning opportunities due to the diverse coverage of subject material and the inclusion of specialist researchers on the teaching body. The use of hands-on laboratory practical sessions coupled with an informed lecture series would further allow students to put theory into practice. Finally complimentary tutorial sessions covering analysis tools, both computational development tools and experimental metrological equipment, would be built-in providing an opportunity for students to find an area in which they excel. The initial concept, as shown in figure 1, was considered to be sound though potentially lacking "punch" in its intended outcomes.

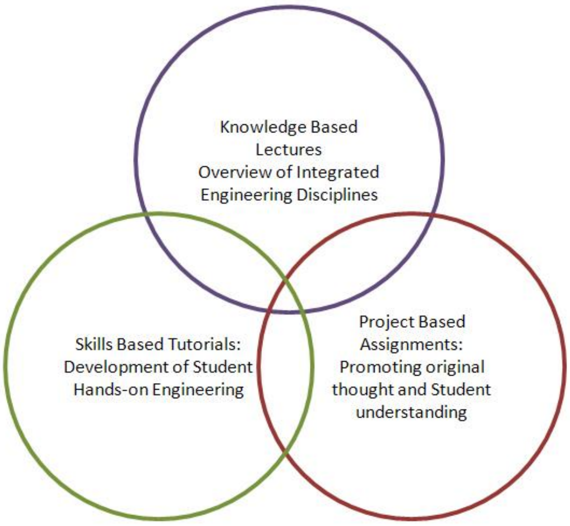

Figure 1. Conceptual interactions of the Microengineering & Microtechnology module.

As a result of the post development analysis it was perceived that the model followed by the Massachusetts Institute of Technology's CDIO syllabus could be implemented to further strengthen the modules structure and emphasise the core principles of the module with the aim of reinforcing the intended learning outcomes of the MTech module.

4. Applying the principles of CDIO

The CDIO Initiative is designed as a template which can be adapted and adopted by any university engineering department. As an open architecture "framework" CDIO is available to all university engineering programs and the platform can be adapted to their specific needs. Participating universities (often referred to as "collaborators" within the CDIO literature) regularly develop materials and approaches that are shared across a multitude of universities.

For the purpose of this study it is not our aim to fully apply CDIO but rather to encompass the philosophy of the approach. It may be considered that this process may form an initial trial in advance of further analysis of CDIO and its application to the engineering courses at the UoH. In this regard while CDIO is considered to be a whole programme approach; a means of developing a series of modules each targeted and developed in order to achieve a specific aspect of the overall CDIO aim, this study will instead distil the concepts and processes embodied by CDIO, condensing them where possible and applying these to a single module structure. This study will assess whether this distilled process can successfully be applied to a single module, or whether the CDIO approach can only be applied on a whole programme basis.

In order to extract the core information of the CDIO approach it is necessary to appreciate the complete CDIO adoption process (see figure 2).

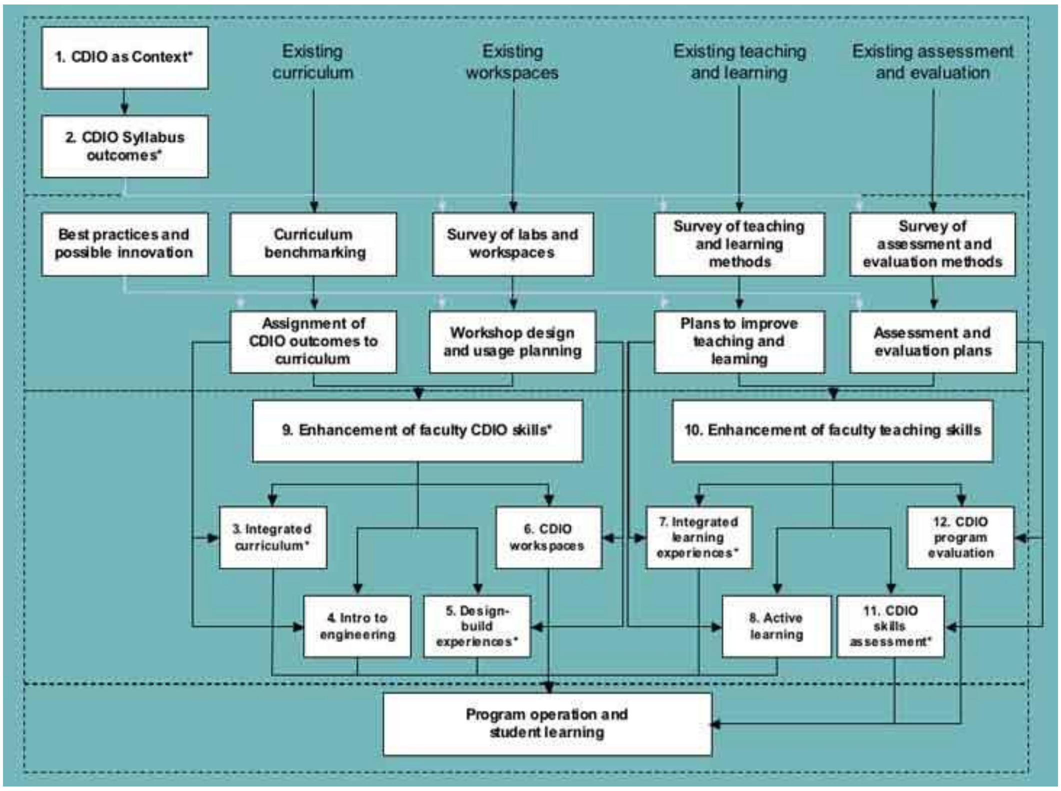

Figure 2. Diagram outlining the complete CDIO adoption process (Crawley, 2001)

The adoption process as highlighted in figure 2 provides a clear managerial structure for the adoption of CDIO. The starting point for this lies in the application of twelve successive standards. Broadly these are as follows (Crawley, 2001):

1. CDIO as Context: Adopt the principle of Conceiving, Designing, Implementing, and Operating as the context for engineering education.
2. Syllabus Outcomes: Specific, detailed learning outcomes for personal, interpersonal, and product and system building skills, consistent with program goals and validated by program stakeholders.
3. Integrated Curriculum: A curriculum designed with mutually supporting disciplinary subjects, with an explicit plan to integrate personal, interpersonal, and product and system building skills.

4. Introduction to Engineering: An introductory course that provides the framework for engineering practice in product and system building, and introduces essential personal and interpersonal skills.
5. Design-Build Experiences: A curriculum that includes two or more design-build experiences, including one at a basic level and one at an advanced level.
6. Workspaces: Workspaces and laboratories that support and encourage hands-on learning of product.
7. Integrated Learning Experiences: Integrated learning experiences that lead to the acquisition of disciplinary knowledge, as well as personal, interpersonal, and product and system building skills.
8. Active Learning: Teaching and learning based on active experiential learning methods.
9. Enhancement of Faculty CDIO Skills: Actions that enhance faculty competence in personal, interpersonal, and product and system building skills.
10. Enhancement of Faculty Teaching Skills: Actions that enhance faculty competence in providing integrated learning experiences, in using active experiential learning methods, and in assessing student learning.
11. Skills Assessment: assessment of student learning in personal, interpersonal, and product and system building skills, as well as in disciplinary knowledge.
12. Program Evaluation: A system that evaluates programs against these twelve standards, and provides feedback to students, faculty, and other stakeholders for the purposes of continuous improvement.

The MMRG employed both top down and bottom up approaches to the application of the 12 standards. With the exception of standards 11 (Skills Assessment) and 12 (Programme Evaluation) the remaining standards can be applied and assessed during the development stage of the module. Standards 11 and 12 have been implemented at the design and development stage however by default these are reflective standards and successfully attaining these can only been achieved at the end of the planned delivery period for the MTech course (May 2012).

5. Adopting the Standards

5.1 Standards 1 and 2

The initial process requires that standards 1 and 2 are adopted at a corporate philosophical level, subsequently the context, program aims, and specific goals for learning should be outlined.

In this instance the MTech module is positioned as a second semester final year module, thus it should be considered as one of the last remaining taught modules before students graduate and either enter further education or engineering employment. In this context the MTech module emphasises that each student is expected to work in collaboration with all other group members, to identify technical issues and solutions together, and to share the decision-making processes – key skills required for industrial collaborative engineering work. Group work is managed through an online repository of group discussions, working documents and meeting information (agenda and minutes as required). Individuals allocate team members an anonymous Peer Assessment mark (moderated by the teaching body) related to the involvement, attitude and output of each member in the team. It is also clearly communicated to students that it is not sufficient for each student to do their own work in isolation – each student should also take part in the group discussions and decision making, provide work at the agreed time and to help others within their group as required.

The programme aim as indicated by the Definitive Module Document (School of Engineering and Technology, 2011) are set out as follows:

- To develop an understanding of the principles required for innovative, integrated microengineering design and manufacture.
- To further develop students' ability to work in multidisciplinary teams to design a microengineering product.

Furthermore the specific learning outcomes are split into two primary categories, Knowledge & Understanding and Skills & Attributes, whereby a successful student should be capable of the following in order to satisfying the Knowledge and Understanding outcomes:

- Demonstrate an understanding of the engineering principles appropriate to the design of a microengineering product
- Demonstrate an understanding of the manufacturing considerations particularly appropriate to a microengineering product

and capable of the following in order to satisfy the Skills & Attributes outcomes:

- Apply appropriate analysis techniques to assessing the performance of a microengineering product.
- Work effectively in a multi-disciplinary team and communicate the development and outcomes of individual, as well as group project, work.

Subsequently the initial program outline was benchmarked against four key components: overall curriculum, use of workspaces, specific approaches to teaching & learning and finally assessment practices.

5.2 Standards 3 to 12

While Standards 1 and 2 are primarily philosophical, standards 3 – 12 require the practical implementation of the module design and the identification of key themes and resources was the primary driver. In each of the key areas (Curriculum, Workspaces, Teaching & Learning and Assessment) the module design was analysed and restructured, areas for improvement where identified and redesigned leading to activities that satisfy the CDIO Standards 3-8. Specifically, the resultant Microengineering & Microtechnology module provides both mechanical and electrical engineers with a base understanding of the principles required for innovative, integrated microengineering design and manufacture. The core of the module is a case study led group project focussing on the design of a microfluidic pump (itself a research output from the MMRG). The individual members of the project groups follow a documented plan that integrates CDIO required skills with technical disciplinary content and exploits the appropriate disciplinary linkages. This is supported by appropriate inclusion of learning outcomes in both formal and informal study requirements. In this instance formal study is taken to mean study which dictates a specific structured process and submission, informal study only dictates the submission requirement encouraging students to develop the process required to satisfy the outcome. Both faculty staff and students alike are aware of the intended learning outcomes of the curriculum, reiterated at the start and end of each formal teaching session.

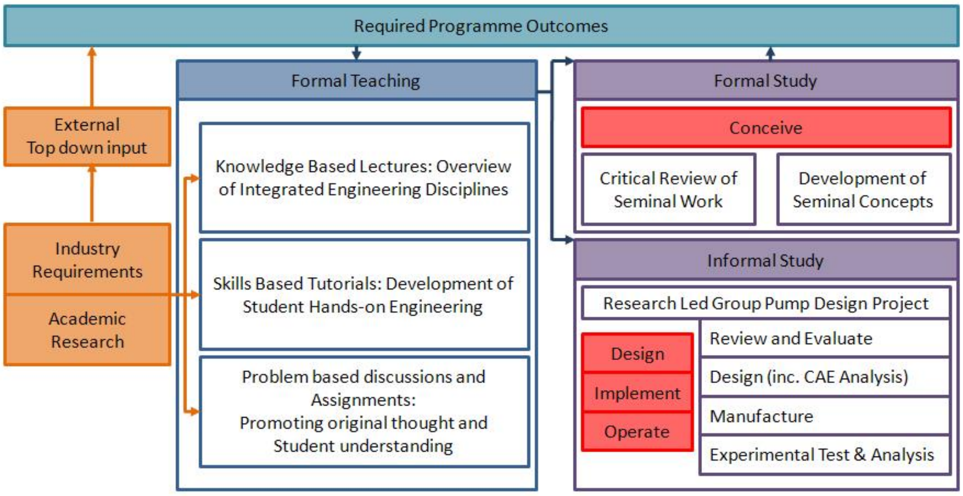

Figure 3. Diagram outlining the complete CDIO adoption process

The group project aspect of the module incorporates learning experiences that introduce essential personal, interpersonal, and product and system building skills where students acquire the learning outcomes described in CDIO Standard 2. The MTech module, being an elective course, engages students at the highest level in their chosen field of study; this is encouraged by the application of directed class discussion and guided by formative assessment of understanding via survey or electronic voting system (EVS) during seminar sessions, the use of this technology has been found to promote interactive engagement, helping to launch peer discussions and enable contingent teaching (Draper, 2004). In the case of the MTech course the opportunity for contingent teaching is of high importance based on the mixed background and prior knowledge of the student body.

The group project leads to one fully realised design-build experience during the course of the module curriculum; this design-build exercise requires co-curricular support at a peer level for design-build and includes support from the research laboratory staff. Finally concrete learning experiences are emphasised by the self-directed group roles which provide the foundation for subsequent learning of specific disciplinary skills. Throughout the module students have access to adequate spaces equipped with modern engineering tools, in particular computer aided software analysis tools, however the students are also encouraged to develop an understanding of the manufacturing processes of Microtechnology via access to a class 1000 microfabrication clean room.

Students are encouraged to be active learners, directed by a project brief and intended outcome but with student led flexibility in the means of satisfying the brief. Furthermore students are required to accurately document this process and self-report as well as self-assess (via moderated peer assessment). This inclusion of self and peer assessment processes has been shown to be an effective method of encouraging student learning (Falchinov, 2000; Sadler, 2006).

To ensure further comprehensive completing on the CDIO requirements additional measures where put in place to strengthen the program and enhance faculty competence in teaching, learning and assessment (Standards 9 and 10). By design the MTech module incorporates the output of research staff that have themselves shown competence in personal, interpersonal, and product and system building skills. This is demonstrated to students through the use of previous research outputs and publications relevant to the MTech project. Being able to draw upon physical engineering output communicated the experience in engineering practice of the teaching staff. Furthermore each member of staff teaching on the MTech has attained post doctorate level academic qualifications; to support this staff have undergone additional Continuous Professional Academic Development (CPAD) in learning and teaching.

The final requirements for satisfying the CDIO criteria are centred on assessment and evaluation (standards 11 and 12). The assessment process applied to MTech includes continuous assignments from the outset, each targeting a specific skill and building on the concepts embodied by the formal teaching session, in all cases the students are informed of the specific learning outcomes targeted by the assessment. Furthermore to encourage diverse ways of learning a variety of separate assignment types cover each of the learning outcomes and provide a number of mechanisms to instil these learning outcomes in each of the students. The overall module classification attained by the student is determined based on reliable and valid data gathered during the course of the module. Two individual assignments are allocated in weeks 1 and 3, these marks are used to form a baseline of the individual and to identify potential areas of weakness. These are flagged and individual feedback is provided for general development (applicable to all assessed modules) and specific development within the MTech module. Continuous learning is assessed via weekly class test using the electronic voting system (EVS). Group work consists of submission of key components at appropriate developmental milestones (Concept development, theoretically analysed designed ready for manufacture, group report, and final presentation). The final report is submitted jointly with each individual contribution clearly identified. In this way individuals are recognised not only for their own abilities but also their contribution to the success of the project.

Finally the MTech module has been constructed with the input from a wide range of key stakeholders, each of whom has individual responsibility for the evaluation of key components of the course. Program evaluation methods, such as EVS, are built into the core of the module to gather supporting data from students during the course. Instructors, program leaders and other key stakeholders have identified mid points during the module where an evaluation of progress can be evaluated and documented; this will form the basis of data-driven changes as part of a continuous improvement process.

Result of the process

Based on an initial design for a research informed module in microengineering and microtechnology and we have systematically applied the concepts embodied by each of the standards outlined by the CDIO approach. The application of the CDIO structure highlighted limitations in the initial consultancy process for the module design.

Specifically a number of principles of good practice as outline by Chickering and Gamson (1987) required further consideration, these being:

- encouraging active learning
- providing prompt feedback
- emphasizing time on task

The application of the CDIO standards has resulted in an undergraduate module that now incorporates all seven of the principles of good practice including those outlined above. The module communicates a high expectation of the students, with directed study and assignment commencing with the start of the module, feedback is provided both formatively and summatively as appropriate to the development of both the assignment structure during the course as well as the student interest level and promotes further reading with directed key texts. The final structure for MTech delivery is shown in table 1.

Week No.	Lab/Prac Topic	Lecture Topic	Seminar Topic	Notes inc. Assignment Set and Due dates
1	Introduction to MTech	Introduction to Microengineering	Case study – Microfluidic pump project In Class Test (ICT -EVS)	Group Report set (A1) Group Photomask (A2) Journal Analysis (A3)
2	Computer Aided Engineering (CAE) intro	Microfluidics	Microfluidics in the laboratory Vs. the real world. ICT -EVS	A3 Due Group Role Form Due
3	CAE Tutorial – CAD, CFD, CAE	Further Microfluidics	Experimental Microfluidics. ICT -EVS	Journal Analysis (A4) A3 Generic Feedback
4	CAE Tutorial – CAD, CFD, CAE	Materials for Microengineering	Material choices and design limitations. ICT -	A4 Due
5	CAE Tutorial – Drop in session	MEMS 1 (Mechanics)	Historical significance of MEMS devices. ICT -EVS	Peer Review 1 Due *Review interactions between Materials, MEMS 1 and MEMS 2*
6	CAE Tutorial – Photomask	MEMS 2 (Electrical)	The commercial application of MEMS. ICT	
7	CAE Tutorial – Photomask	Metrology	Metrology: design support before, during & after development. ICT -	A2 Due *Book Open Access Lab*
8	CAE Tutorial – CAD, CFD, CAE	An Overview of Microfabrication	Turning the virtual into reality – complexities and intricacies. ICT -EVS	Peer Review 2 Due A1 Outline and Literature Review
9	CAE Tutorial –	Core Microfabrication	Review of Group Project. ICT -EVS	*Complete Lab work* Presentation set (A5)
10&11	***Vacation Easter Break***			
12	CAE Final wrap	Process	Final Report Discussion	A1 Due
13	A5 Project Presentations Due			Peer Review 3 Due

Table 1. Final schedule for Microengineering and Microtechnology as developed using the CDIO

The result of this process was the successful creation of a Microengineering & Microtechnology module, offered as an elective course for final year engineering students studying mechanical and electrical engineering at the University of Hertfordshire from 2011. The initial uptake has resulted in 40 students opting to study Microengineering & Microtechnology in 2011, more students than either of the alternative two elective modules running at the same time. The module has subsequently averaged 42 students per year over the 5 years the course has been running.

Alongside pass average and external examination of the programme the University also collates individual module feedback from current students via end of programme questionnaires. This process provides a qualitative assessment of the programme from the student perspective. During the 5 year period discussed two variations of the questionnaire have been used, the Module Feedback Questionnaire and the Student ViewPoint Questionnaire. In both cases specific, module related, questions were identical, scored by students from 0 – 5 and their application and implication on the module can be compared. The relevant questions from the MFQ/SVP questionnaires, question 1 – 8, are as follows:

1. The module provides learning opportunities which enable the learning outcomes to be achieved.
2. The module is well organised and running smoothly.
3. E-learning facilities (e.g. StudyNet) are contributing usefully to my learning on this module.
4. The module is intellectually stimulating.
5. The criteria used in marking have been clear in advance.
6. Feedback on my work is helping me to clarify things I did not understand.
7. Feedback on my work is prompt.
8. I am able to contact staff when needed (including email and telephone as well as face to face).

Table 2. End of programme questionnaire (across all modules at the University of Hertfordshire).

Student feedback was sought at the end of each semester for all engineering modules using either SVP (Student View Point, 2011/12 & 2012/13) or MFQ (Module Feedback Questionnaire, 2013/14, 2014/15 & 2015/16) with the CDIO based MTech module recording an average of ~18% higher that departmental average for the first four year period, by comparison the module received an average score ~15% higher than the University as a whole for the period. Initial indications are that changes made to the programme during 2015-16 academic year concerning feedback delivery mechanisms (online delivery) have potentially affected the module score for both questions 6 & 7.

Q no.	2011-12			2012-13			2013-14			2014-15			2015-16		
	U	S	M	U	S	M	U	S	M	U	S	M	U	S	M
1	4.13	4.17	4.35	4.24	4.15	4.75	4.13	4.05	4.70	4.20	4.19	4.57	4.20	4.17	4.38
2	3.81	3.95	4.35	3.90	3.90	5.00	4.00	3.94	4.60	4.10	4.06	4.39	4.10	3.98	4.31
3	3.69	4.10	4.30	3.85	4.04	5.00	3.96	3.97	4.60	4.12	4.14	4.38	4.10	4.13	4.54
4	3.73	4.04	4.55	3.80	3.97	4.50	4.01	3.85	4.50	4.09	4.07	4.42	4.07	4.00	4.15
5	3.56	3.92	4.15	3.70	3.87	5.00	3.89	3.82	4.60	4.03	4.04	4.44	4.03	3.99	4.23
6	3.20	3.83	4.25	3.47	3.81	5.00	3.67	3.52	4.70	3.87	3.88	4.42	3.85	3.72	3.85
7	3.10	3.85	4.30	3.44	3.80	4.75	3.69	3.61	4.20	4.01	3.99	4.41	4.01	3.88	3.92
8	3.82	4.13	4.50	4.14	4.08	5.00	4.22	4.09	4.80	4.32	4.27	4.63	4.29	4.20	4.23
Avg.	**3.63**	**4.00**	**4.34**	**3.81**	**3.95**	**4.88**	**3.95**	**3.86**	**4.59**	**4.09**	**4.08**	**4.46**	**4.08**	**4.01**	**4.20**

Table 2. End of programme questionnaire results compared from 2011 through 2015. U=University wide average, S= School wide average & M= Module average collated from MFQ and SVP data. Light Green – Dark Green represents lowest to highest score per academic year. (University of Hertfordshire Centre for Academic Quality Assurance (CAQA), 2016 [unpublished, personal communication])

While the final distribution of module classification is indicative of the work ethic and input from individual students it is clear to see that the expectation on students can be considered "challenging but achievable". This is evidenced by the average grade achieved by students, falling into the lower segment of the 2nd Class category (60 – 69%) but with a zero failure rate over the 5 years of the programme (below 40%). The average student mark for this module has remained consistent from the outset and averages 63% with an absolute standard deviation of 0.64 (Chart 1).

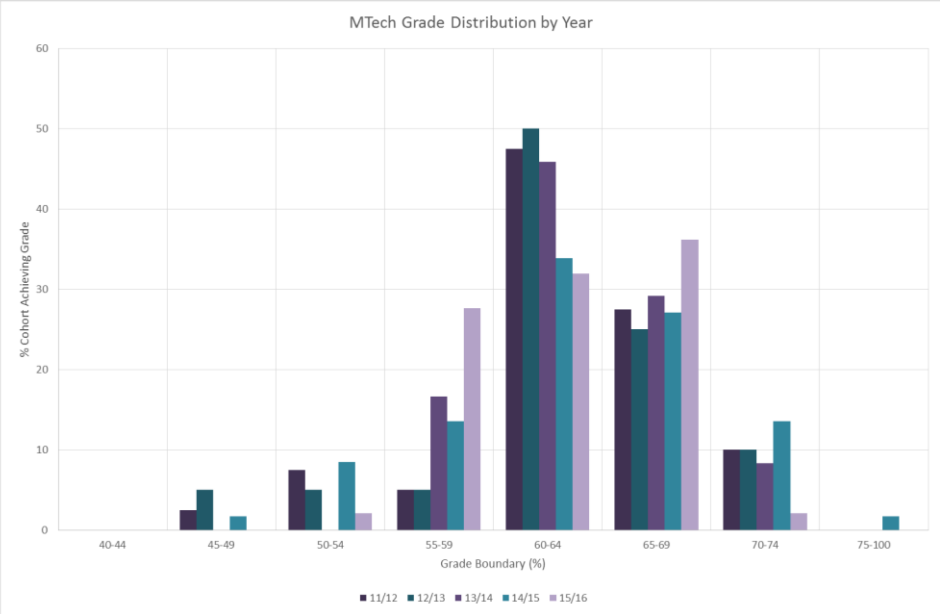

Chart 1. End of programme grade distribution over the first 5 years of Microengineering & Microtechnology module.

Conclusion

We have designed and developed a research informed module in microengineering and microtechnology and we have successfully implemented the concepts embodied by the CDIO approach;

> *"Conceive, design, implement & operate complex value-added engineering systems in a modern team-based environment"*

However during development of the course it was necessary to distil the fundamental concepts embodied by CDIO as the approach is primarily design to be applied on a "whole curriculum" level. The final proposal has resulted in a module structure that embodies a number of principles of good practice from the education literature. The inaugural run of the Microengineering & Microtechnology module was offered as an elective course for final year engineering students studying mechanical and electrical engineering at the University of Hertfordshire. The initial uptake resulted in 40 students opting to study Microengineering & Microtechnology, more students than either of the alternative two elective modules running at the same time. The module has subsequently continued to attract a similar proportion of students from both mechanical and electrical cohorts. The programme was offered exclusively to these cohorts from 2011-2012 until 2013-14. From 2014 onwards the programme has been extended and is now included as a compulsory component on two new degree programmes MEng/BEng Mechanical Engineering & Mechatronics (inaugural year 2014) and MEng/BEng degree in Biomedical Engineering (inaugural year 2015). With positive feedback from students, staff, external examiners and validation teams this module, with the aim to be innovative and research led, can be considered a success. The implementation of CDIO approaches coupled with research informed teaching can lead to the development of research and development skills and learning as evidenced by the results of the individual students on this programme.

Further work

To further validate the teaching of research skills and learning it is recommended that a future review of the Destinations of Leavers from Higher Education (DHLE) data could be conducted. This would aim to establish whether graduates from this programme are more likely to enter into research orientated further study or employment. With low graduate numbers at present it is anticipated that this study may only provide relevant data once graduate numbers from the MEng/BEng Mechanical Engineering & Mechatronics and MEng/BEng Biomedical Engineering are included in the assessment.

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References

Chickering, A. W., and Gamson, Z. E. (1987). Seven principles for good practice in undergraduate education. AAHE Bulletin 39: 3 -7.

Crawley, E.F. (2001) “The CDIO Syllabus – A Statement of Goals for Undergraduate Engineering Education”, http://www.cdio.org

Crawley E. F. (2002), “Creating the CDIO Syllabus, a universal template for engineering education”, 32nd ASEE/IEEE Frontiers in Education Conference, Nov 6-9, 2002, Boston.

Crawley, E.F, Malmqvist, J., Ostlund, S., & Brodeur, D. (2007). Rethinking Engineering Education: The CDIO approach. Springer.

Draper, S. W. and M. I. Brown (2004). "Increasing interactivity in lectures using an electronic voting system." Journal of Computer Assisted Learning 20(2): 81-94.

Falchikov, N. and Goldfinch, J. (2000). "Student peer assessment in higher education: A meta-analysis comparing peer and teacher marks. " Review of Educational Research, v. 70, pp. 287-322.

Feynman R.P. (1992) There's Plenty of Room at the Bottom. Journal of Microelectromechanical Systems, Vol. 1, No. 1, March 1992, pp. 60-66

Humboldt, W. von (1970), ‘On the spirit and organisational framework of intellectual institutions in Berlin’, Minerva 8, pp. 242 – 267 [original 1810]

Johnston, I.D., Tracey, M.C., Davis, J.B. & C. K. L. Tan. (2005) Microfluidic Throttle Pump Employing Displacement Amplification in an Elastomeric Substrate. J. Micromech. Microeng. 15, pp. 1831-1839

Sadler, P. and Good, E. (2006). "The impact of self- and peer-grading on student learning." Educational Assessment, v. 11, n. 1, pp. 1-31

School of Engineering & Technology, (2011). Definitive Module Document Microengineering & Microtechnology 6ENT1022. Hatfield: University of Hertfordshire.

Springer, L., Donovan, S. S., & Stanne, M. E. (1999). Effects of small-group learning on undergraduates in science, mathematics, engineering, and technology: A meta-analysis. Review of Educational Research, 69(1), 21-51.

The Higher Education Academy (2006) The UK Professional Standards Framework for teaching and supporting learning in higher education. YORK: Higher Education Academy.

Xia, Y. and G. M. Whitesides (1998). "Soft Lithography." Annual Review of Materials Science 28: 153 - 184