INTEGRATED SYSTEMS DESIGN EDUCATION

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ABSTRACT

Integrated Systems Design refers to the design, development and integration of products and systems. Central to successful ISD is the co-ordination and incorporation of contributions from many professions and technologies. This presents challenges for organisations in the composition and supporting of integrated systems. One challenge is that many engineering graduates enter industry with little or no explicit knowledge of ISD and systems thinking. This in turn results in reduced organisational efficiency and increased post employment training. The hypothesis is simple; provide engineering students with ISD principles and you will provide organisations with graduates who can contribute to industry quicker. The Royal Academy of Engineering appointed a Visiting Professor at the University of Strathclyde, with the overall aim to produce a pilot scheme integrating systems design education into engineering programmes. This paper charts the key project findings, beginning with a review of ISD practice within industry and academia. From this review, an analysis matrix was developed and piloted allowing Universities to analyse the extent ISD is being taught and identify gaps in knowledge.

Keywords: systems engineering, integrated design, education

1. INTRODUCTION

Integrated Systems Design (ISD) is a process developed to create improved products and services through the optimised design, development and integration of all processes and systems used in creating products and services. To compete globally, organisations are increasingly developing major systems which are inherently more complex and likely include contributions from many professions and technologies. This trend is seen across many market sectors from Defence to Healthcare and from Aerospace to Energy. Major companies operating in this environment are often acting as system integrators which require adoption of new ISD skills for their employees and for their supply chain. The challenge that organisations are facing is many engineering graduates enter industry with little or no explicit knowledge of ISD and systems thinking. For these organisations, this leads to expensive and time consuming post graduate training programmes required to ensure these graduates are able to work within these globally competitive environments.

The successful integration of complex systems is not a modern issue and the roots can be traced back into history, technical papers relating to military applications began to appear in the late 1930s with increased study during the Second World War [1]. In his paper “Inventing Systems Integration” Sapolsky [2] gives a detailed account of the advent of systems integration from the American perspective. The paper charts the military history, from WWII applications through to cold war era where the author argues that the need for advanced and complex weapons systems led to the American military practicing systems integration skills such as conceiving, designing and managing the development and deployment of large weapons and strategic systems involving multiple disciplines and many participating organisations.

With the integration of more complex systems whether it is for military or commercial purposes, comes the need for modelling of the integration process. Several process models exist for the design of complex systems, many of which originate from the development of software systems. One commonly used model is the ‘V’ or ‘Vee’ diagram shown in Figure 1. The ‘V’ model illustrates the need for feedback and iteration between successive stages and the relationships between the early design activities and the subsequent integration and testing, emphasising that the whole process must be carefully planned from the start. The ‘V’ Systems Engineering Model is emerging as the de facto standard way to represent systems engineering projects and since it was first introduced has been refined and applied in many different industries [3]. As shown in figure 2 the ‘V’ systems engineering approach defines project requirements before technology choices are made and the system is implemented. On the left side of the ‘V’, the system definition progresses from a general user view of the system to a detailed specification of the system design. The system is deconstructed into subsystems, and the subsystems are split into components – a large system may be represented by smaller and smaller pieces through many layers. As the system is deconstructed, the requirements are also split into more specific requirements that are allocated to the system components.

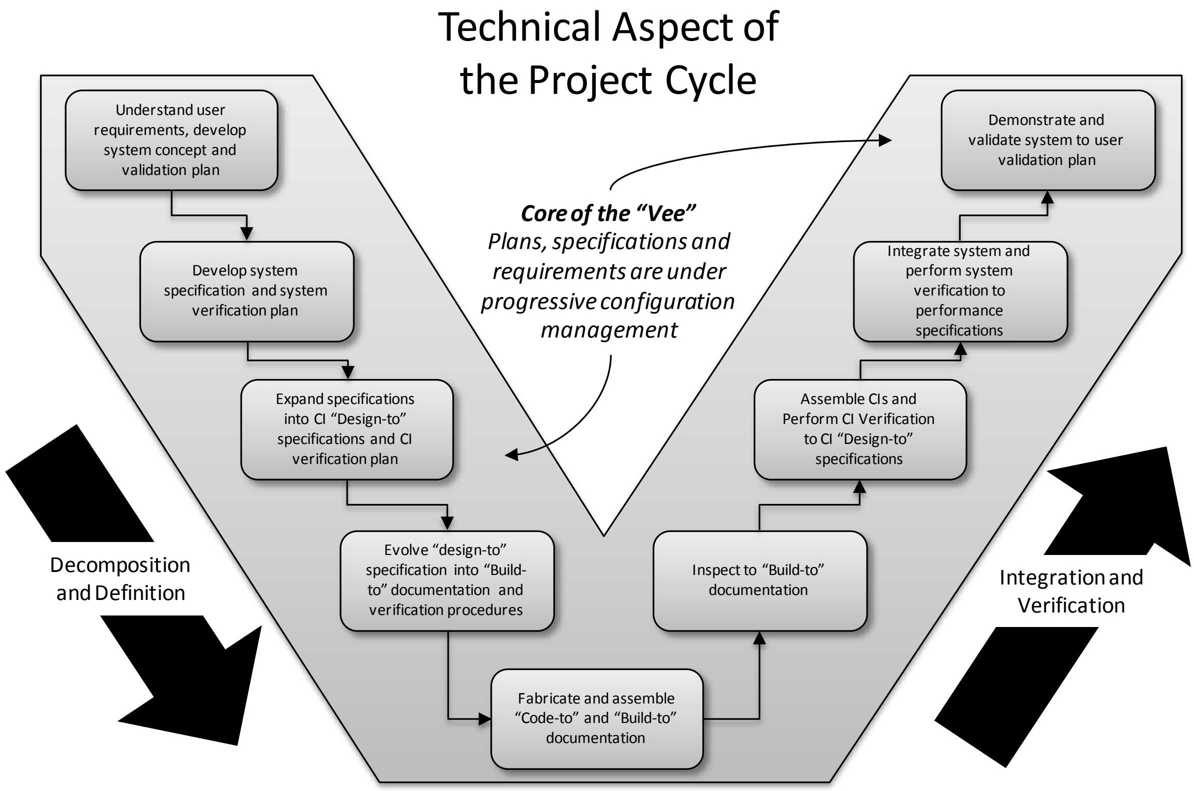

Figure 1. The “V” Model of Systems Integration [4]

As development of the project progresses, a series of baselines are established that read across and effectively support the steps that follow. For example, the development of the system specification and system verification plan in step 2, reads across directly to step 8 where the integrated systems are verified and validated against the specification. Similarly, the ‘build to’ documentation developed in step 4 of the process are used as the inspection baseline for the documentation. Essentially the basic principle of the ‘V’ model is that the stages on each side of the model are intrinsically linked. The hardware and software are implemented at the bottom of the ‘V’, and the components of the system are then integrated and verified in iterative fashion on the right. Deconstructing the V diagram, the process can be simplified to five basic activities, Design, Partition, Manufacture, Integrate and Test. Of these activities Design, Manufacture and Test will be found as core subjects in most engineering degree courses. The problems associated with increasing system complexity introduce the need for the other two activities, namely partitioning and integration [5].

The hypothesis presented in this paper is simple; provide engineering students with systems thinking principles and experience at the undergraduate stage in their academic studies and you will provide organisations with graduates able to contribute to the business with more immediate impact. The realisation of this objective has been the focus of recent Royal Academy of Engineering (RAEng) studies and the primary subject for their Visiting Professor schemes. In 2008, the RAEng appointed a Visiting Professor in Integrated Systems Design at University of Strathclyde. A project was agreed with the overall aim to produce a cross-faculty pilot scheme to integrate system design into Faculty programmes. This paper charts some of the key findings from this project.

2. METHODOLOGY

The methodology adopted for this research consisted of four phases as demonstrated in figure 2. Each of the phases are subsequently described in further detail.

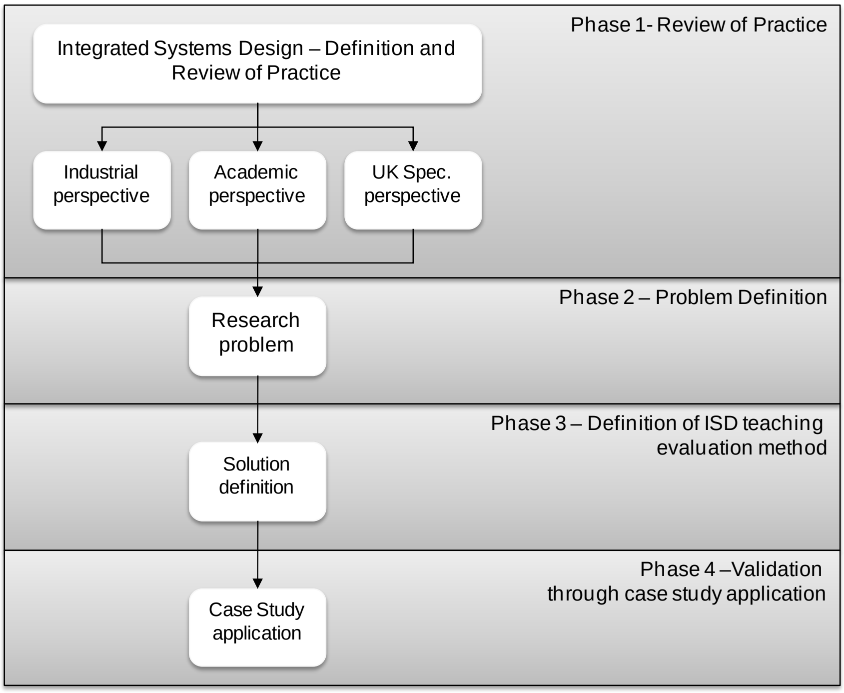

Figure 2. Research Methodology

2.1 Phase One: Review of practice within academia and industry

The first phase of this project aimed to establish the application of Integrated Systems Design teaching principles within academia. This involved undertaking a review of current published literature and engineering design course structures within UK and internationally based Universities and Colleges, and undertaking of case studies. In the context of this paper, the adoption of the case study approach present an opportunity to understand, first hand, the Integrated Systems Design teaching practices of UK universities within the engineering design context. In addition this phase involved interaction and discussions with major UK and international industrial engineering companies spanning several sectors such as aerospace, power generation, marine and electronics.

To generate case study data sets for analysis, open interview techniques were identified as the primary method of data a collection, and in particular, semi structured interviews to establish the level of awareness of ISD teaching. In qualitative research, the conducting of open interviews is becoming more prevalent and widely used as the preferred method for data collection [6]. An open interview does not follow a set sequence of questions like a structured interview. Instead the interview relies on discussion between the interviewer and the interviewee with the questions being asked incidentally or on an ad-hoc basis. Semi-structured interviews are a variation on the open interview style in that this technique involves the interviewer developing an interview guide or set of points which he or she wishes to cover during the course of the interview; however the questions themselves remain relatively open. The recognition is that the interviewee's views and opinions are more likely to be expressed in an open or semi-structured interview setting than in formal and standardised interview situations or through the use of questionnaires [6-7].

2.2 Phase Two: Problem definition

Phase two of the project looked to build upon the review of practice gathered to further define the research problem and ISD requirements from both an industrial and academic viewpoint. The definition of the problem also helps to gain a perspective on the metrics used to measure the validity of the solution.

2.3 Phase Three: Development of ISD teaching evaluation method

Utilising the findings from phases One and Two, the third phase of the project looked to develop a method of analysing the level of ISD teaching currently undertaken within academic departments and subsequently a framework which will provide a check list for disciplines / departments to ensure full consideration is given to system integration in designing or introducing new courses.

2.4 Phase Four: Validation through case study application

The fourth phase of the project aimed to validate the ISD identification method through a case study analysis examining the engineering degree courses available within UK University engineering design departments, against the accreditation learning objectives as detailed within the UK-SPEC higher Education guidelines. The resulting data sets presented two perspectives on ISD teaching: 1) The level of ISD principles embedded in the engineering courses through the UK-SPEC accreditation learning objectives and 2) The identification of future work on ISD required within the department under study.

3. BACKGROUND / LITERATURE REVIEW

The first phase of this research programme aimed to explore market trends and drivers with regard to systems thinking and integrated systems design. This has been approached from analysing the relevant published literature, interaction with industry and government bodies and discussion with academic colleagues. These strategic reviews, supported by a discussion with senior industrialists were undertaken to understand the support for understanding of complex integrated systems amongst the technical graduate community. The following sections provide detail on these reviews.

3.1 Review of practice in industry and government bodies.

As part of the review of industrial practice, discussions were held with major multinational engineering firms. These discussion sessions were conducted as semi-structured interviews and used to help inform the direction of the project. The companies involved in the discussion sessions, although operating in sometimes vastly different industry sectors (such as Aerospace, Energy, Marine), communicated very similar issues in terms of employing staff, and in particular graduates, with the most appropriate skill set. There was strong agreement across these companies in the need for ISD-ready graduates, and most agreed that this should be embedded into undergraduate engineering programmes. There was also strong support for project based approaches, particularly if the projects can have industrial or market sector relevance. The feedback from industry correlates strongly with the review of literature and thus supports the need for this programme. There is further work required to consider other industries and the SME sector.

The aim was for the phase three study to include a brief review of the UK Government’s key policy on Defence, Energy and Science, highlighting the place of system integration. This included reviewing White Papers on defence [8] and Energy [9]. In both these policy areas the need for integrated defence systems and integrated energy systems are considered critical. In the US these systems integration approaches have been used with success in transport [3] and in social schemes [1]. These strategic reviews, supported by the discussions with senior industrialists support strongly the need for understanding of complex integrated systems amongst the technical graduate community.

3.2 Review of practice in academia and learned bodies.

Through a review of the published literature the authors sought to understand the history, evolution, current thinking and related research areas relevant to integrated systems design. From early efforts at Lockheed Martin’s Skunk works [10] and Admiral Rickover’s first introduction of project management [11] the benefits of integrated teams who can work in complex systems environments have been clear. In academia this has evolved into project based and experiment based learning programme approaches [5, 12-16]. Integration, co-ordination and communications within project teams for complex projects have also been studied extensively, with strong recommendations to support integrated working [17-19].

There appears no extensive literature detailing how and at what level integrated systems design should be taught. A literature search (including engineering journals and conference proceedings) highlights that although many principles and models of systems engineering exist and are well documented, there is very little literature prescribing the teaching of integrated systems design. The literature available focuses not on the integration of systems at an engineering project level but specifically on the integration of systems within the electrical engineering and software domains [20-23]. As highlighted previously, integrated systems development is not a new phenomenon, however the need for such approaches is perceived to be growing within today's global organisations [24]. It would appear that the reason for so little prescriptive teaching in ISD arises from the debate as to the level at which the subject should be taught. Hambleton [14] in his address to the Defence Engineering Group tells us that:

> *"no formal teaching is attempted at school. Children experience systems in life and at play. Some school topics, such as set theory, espouse system principles. Could a structured systems approach, with examples, be included?"*

It appears to be generally accepted that the principles of systems integration is too complex a subject to be taught at the required detail in school education and at undergraduate level most engineering courses focus on single disciplines [5]. Traditionally, engineers encounter the need for systems integration after a number of years of industrial experience in their initial discipline [3, 25]. Given the duration of large-scale projects, and the need to accrue the necessary experience and knowledge to become a successful systems engineer, the process of gaining the appropriate skill-sets through the traditional experiential route is a long process. Therefore are the principles of systems integration best taught at postgraduate level? A brief internet search through the Universities & Colleges Admissions Service (UCAS) and UK Postgraduate Application and Statistical Service (UKPASS), the graduate course listing website, tells us that of the 400+ UK based courses addressing the issues of systems engineering and integration only 31 are taught at undergraduate level whilst the rest are at postgraduate level [26-27] giving clear indications that this is where most systems focused courses exist. In many cases these postgraduate courses are born from industrial needs and as such are often designed for specific sectors of industry such as energy, defence, aerospace or marine. The focus of these systems courses can be on building up the student's multi-disciplinary skill set and appreciation of the use need for such skills and it would seem that the best results are most readily achieved at the postgraduate level, after the student has developed a sound engineering based knowledge.

3.3 Summary

This review does not pertain to be an all encompassing analytical look at systems design thinking as a subject and the methodologies to apply this in practice. Instead this review serves to highlight from current literature and relevant industrial bodies that there is a specific need for an understanding of how many complex products can be better by applying the core principles of systems integration. The general feedback from industry supported the literature in placing importance to the need for graduate programmes to incorporate ISD type programmes. In addition this review has surveyed the current status of ISD within the current UK University and college teaching syllabi and found there to be scope for courses or modules designed specifically to teach engineers the fundamental aspects of product systems and their complex interactions. From observation of the current courses on offer it would seem that the UK universities and colleges currently offering teaching ISD at the required depth are teaching the subject predominately at postgraduate level engineering and those offering teaching at undergraduate level are focused on systems engineering principles as a whole and not specifically on Integrated Systems Design. Any university who could offer teaching of these timely and critical aspects of engineering product development at an undergraduate degree level could become the leading UK institution for providing engineering graduates with the skills necessary to tackle the integration problems many of the large scale engineering organisations are currently facing.

4. PROBLEM DEFINITION

The key problem derived from the literature and also other studies seem to be a lack of clarity of Integrated Systems Design. Evidence shows that as a subject ISD is being taught, but the perception is that it is a complicated subject and one which only students who have a rounded and background or education in engineering can fully grasp. The indications are that this perception is incorrect. By analysing the definition of ISD and the principles therein it would seem that students are being exposed to these skills throughout their undergraduate education, the problem may simply be that the institutions are not fully aware that many of the core skills prescribed by the Engineering Council and UK spec guidelines for accreditation of engineering courses do fall under the category of ISD and thus these should be made more explicit.

According to a recent report by the Royal Academy of Engineering [25], the engineers who will lead the design of integrated systems need:

- A sound basis in the science of engineering – the basic physics, chemistry and mathematics on which engineering is founded
- An analytical spirit, which seeks to model, understand, quantify and characterise problems
- Creativity to find innovative solutions and not let the trees distract them from the woods
- An awareness of the many disciplines that impact on system design, from the different branches of engineering through law, commerce, management, logistics and politics
- Strong communication skills to work with: the other engineers that are their peers; managers, financiers, customers and users; and the other trades and professions that make the system work (maintenance technicians, aesthetic designers, ergonomists, assembly workers …)
- Leadership to be able to carry their colleagues with them when they are right and to listen to those colleagues and learn when they are wrong.

All of the above skills are attainable at undergraduate engineering level. In fact, many of the skills listed in the RAEng report are skills commonly found in most engineering graduates. However the differences lie in the fundamental understanding of how systems work together and how these multidisciplinary aspects, required to create successful products, can be capitalised on to ensure the success of the organisation. As mentioned earlier, this level of understanding has previously only been achievable through experience and involvement in projects and as such a critical element of any course pertaining to teach the fundamentals of integrated systems design is the interaction with industry and the practical application of the taught material.

5. DEVELOPMENT OF THE ISD EVALUATION METHOD

Since 2004 accreditation of UK university engineering courses, provided by the Engineering Council (EC) UK, has been seen as a quality stamp on the educational standards of the courses being taught to students. UK Standard for Professional Engineering Competence (UK-SPEC) accreditation helps to ensure that UK engineering education meets industrial needs, as well as aiming to adequately equip graduates with necessary and relevant skills for a career in the engineering profession [28]. Achieving accreditation demonstrates both nationally and internationally the high standard of UK engineering education and provides a basis for educational establishments to review their programmes and to develop excellence in delivery and content. To achieve accreditation, universities integrate a number of learning objectives (LOs) as defined in the UK-SPEC. These include LOs such as:

- Knowledge and understanding of mathematical principles necessary to underpin their education in their engineering discipline and to enable them to apply mathematical methods, tools and notations proficiently in the analysis and solution of engineering problems;
- Ability to apply and integrate knowledge and understanding of other engineering disciplines to support study of their own engineering discipline.
- Understanding of engineering principles and the ability to apply them to analyse key engineering processes;
- Ability to identify, classify and describe the performance of systems and components through the use of analytical methods and modelling techniques;

Upon analysis of the full list of UK-SPEC defined LOs, it would appear that a number of the objectives incorporate many of the fundamental principles of systems thinking. These specific objectives are presented in table 1 along with descriptions. Specific objectives such as *"Ability to apply and integrate knowledge and understanding of other engineering disciplines to support study of their own engineering discipline"* and *"Understanding of and ability to apply a systems approach to engineering problems"* are explicitly defined as core engineering skills which students should acquire, and yet are directly related to systems thinking. In total, of the 24 learning objectives defined by the

UK-SPEC, 11 of these incorporate elements of systems thinking. Therefore this presents a new issue, if the accredited engineering courses are developed using LOs which explicitly contain systems thinking elements, are these courses and individual modules therein communicating these skills to students and industry? In essence do graduates and industrial organisations realise that many of the core elements of UK undergraduate course *do* teach integrated systems design thinking, and thus is the issue simply one of communication? In order to test this hypothesis an analysis matrix was devised which would enable universities and departments to analyse their teaching with respect to ISD.

Table 1. Systems Thinking Related UK-SPEC Learning Objectives

Knowledge and Understanding	
Underpinning science and mathematics, and associated engineering disciplines, as defined by the relevant engineering institution	
US3	• Ability to apply and integrate knowledge and understanding of other engineering disciplines to support study of their own engineering discipline.
Engineering Analysis	
E2	• Ability to identify, classify and describe the performance of systems and components through the use of analytical methods and modelling techniques;
E4	• Understanding of and ability to apply a systems approach to engineering problems.
Design	
Design is the creation and development of an economically viable product, process or system to meet a defined need. It involves significant technical and intellectual challenges and can be used to integrate all engineering understanding, knowledge and skills to the solution of real problems. Graduates will therefore need the knowledge, understanding and skills to:	
D5	• Ensure fitness for purpose for all aspects of the problem including production, operation, maintenance and disposal;
Engineering Practice	
Practical application of engineering skills, combining theory and experience, and use of other relevant knowledge and skills. This can include:	
P3	• Understanding of contexts in which engineering knowledge can be applied (eg operations and management, technology development, etc);
General Learning Outcomes	
The range of general learning outcomes described for graduates from Bachelors programmes will also apply to graduates from MEng programmes. In respect of general transferable skills, the following enhanced outcomes should be expected of MEng graduates:	
G3	• An understanding of different roles within a team, and the ability to exercise leadership;
G4	• The ability to learn new theories, concepts, methods etc in unfamiliar situations.
Specific Learning Outcomes	
In respect of the specific learning outcomes, MEng graduates will also be characterised by some or all of the following (the balance will vary according to the nature and aims of each programme):	
Underpinning science and mathematics, etc.	
S1	• A comprehensive understanding of the scientific principles of own specialisation and related disciplines;
S4	• An understanding of concepts from a range of areas including some outside engineering, and the ability to apply them effectively in engineering projects.
Engineering Analysis	
S6	• Ability to apply mathematical and computer-based models for solving problems in engineering, and the ability to assess the limitations of particular cases within unfamiliar contexts.
Engineering Practice	
S14	• Ability to apply engineering techniques taking account of a range of commercial and industrial constraints.

As presented in figure 3, the analysis matrix correlates the output standards against the individual modules offered throughout each year of the engineering course. One matrix would be used to analyse a course and when the matrices are collated, a total view of the ISD teaching within the department or faculty can be gleaned.

		BEng									
		MEng									
	Modules	Year 1		Year 2		Year 3		Year 4		Year 5	
		56XXX	56XXX	56XXX	56XXX	56XXX	56XXX	56XXX	56XXX	56XXX	56XXX
Output Standards	Underpinning Science & mathematics										
	US3	✓	✓	✓		✓	✓	✓		✓	
	Engineering Analysis										
	E2				✓		✓	✓	✓	✓	✓
	E4	✓		✓		✓	✓				
	EM										
	Design										
	D5	✓	✓	✓	✓		✓	✓		✓	
	DM		✓				✓	✓			
	Engineering practice										
	P3			✓		✓					
	General Learning Outcomes										
	G3				✓					✓	
	G4		✓								
	Specific outcomes (MEng only)										
	S1		✓			✓					
	S4	✓						✓			
	S6		✓	✓		✓				✓	
	S14			✓							

Figure 3. ISD Analysis matrix

Utilising such a method to analyse the level of ISD teaching present in courses not only provides a view of the extent to which systems thinking is being taught, but can also be used to identify the appropriate delivery mechanisms which can be implemented into the courses to ensure greater education in Integrated Systems design.

Through a review of current modules offered by the University of Strathclyde's Engineering faculty it has become apparent that Integrated Systems Design is a subject which is taught implicitly and independently across three key departments; that of Design, Manufacture and Engineering Management, Electronic and Electrical Engineering and Mechanical Engineering. The teaching of this subject occurs with varying degrees of detail and the teaching tends to be confined to integrated modules taught as part of core degree courses or Masters degree courses. Through a series of discussions and interview sessions it was found that lecture staff within these departments use different terminology whilst referring to the subject and core principles for the teaching of the subject are inconsistent. These discussions identified that there is a need for explicit and consistent teaching of Integrated Systems Design across the departments with vested interest in this subject. The case study presented within this paper was undertaken within the Department of Design Manufacture and Engineering Management (DMEM) at the University of Strathclyde in Glasgow, UK. DMEM is an energetic and innovative department aiming to offer broad-based education and research of relevance to meet industrial and commercial needs. DMEM's teaching portfolio covers the whole manufacturing value chain from creative design, engineering design, manufacturing, to management of the entire value system (including operations, supply chain, strategic and technology management) thus encapsulating the principles of Integrated Systems Design. The Department's overarching research mission is "Enabling Total Engineering" through the synergies of product design and development, manufacturing technology and engineering management research. In essence the Department acts as systems integrators pulling specific expertise from other areas (such as Mechanical, Materials, Electrical etc Engineering as well as Economics, Marketing, Management Science, Psychology, HRM) using their know-how to integrate expertise from each specific field to deliver a total solution

Product Design Engineering

		BEng																					
		MEng																					
	Modules	Year 1			Year 2					Year 3						Year 4					Year 5		
		56101	56103	56105	56201	56202	56205	56206	56207	56301	56302	56311	56312	56314	19222	56404	56405	56409	56412	56418	56501	56502	56503
Output Standards	Underpinning Science & mathematics																						
	US3	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓			✓		✓	✓			✓
	Engineering Analysis																						
	E2				✓		✓			✓	✓				✓								✓
	E4			✓		✓	✓		✓	✓		✓				✓	✓	✓	✓			✓	
	Design																						
	D5	✓			✓		✓					✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	
	Engineering practice																						
	P3					✓				✓				✓					✓	✓	✓		✓
	General Learning Outcomes																						
	G3			✓		✓			✓		✓						✓		✓			✓	
	G4	✓						✓							✓						✓		✓
	Specific outcomes (MEng only)																						
	S1																				✓		✓
	S4																					✓	
	S6																						
	S14																					✓	✓

Engineering and Enterprise Management

		BEng																		
		MEng																		
	Modules	Year 1			Year 2					Year 3						Year 4		Year 5		
		56101	56103	56105	56201	56202	56205	56206	56207	56303	56304	56307	56311	56312	19222	56416	56420	56501	56502	56503
Output Standards	Underpinning Science & mathematics																			
	US3	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓		✓	✓			✓
	Engineering Analysis																			
	E2				✓		✓								✓	✓				✓
	E4			✓		✓	✓						✓						✓	
	Design																			
	D5	✓			✓		✓						✓	✓			✓	✓	✓	
	Engineering practice																			
	P3					✓											✓	✓		✓
	General Learning Outcomes																			
	G3			✓		✓			✓										✓	
	G4	✓						✓							✓			✓		✓
	Specific outcomes (MEng only)																			
	S1																	✓		✓
	S4																		✓	
	S6																			
	S14																		✓	✓

Manufacturing Engineering and Technology

		BEng																			
		MEng																			
	Modules	Year 1			Year 2					Year 3						Year 4			Year 5		
		56101	56103	56105	56201	56202	56205	56206	56207	56301	56302	56303	56304	56307	19222	56405	56409	56422	56501	56502	56503
Output Standards	Underpinning Science & mathematics																				
	US3	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓		✓		✓			✓
	Engineering Analysis																				
	E2				✓		✓			✓	✓				✓			✓			✓
	E4			✓		✓	✓		✓	✓						✓		✓		✓	
	Design																				
	D5	✓			✓		✓									✓	✓		✓	✓	
	Engineering practice																				
	P3					✓				✓								✓	✓		✓
	General Learning Outcomes																				
	G3			✓		✓			✓		✓					✓				✓	
	G4	✓						✓							✓				✓		✓
	Specific outcomes (MEng only)																				
	S1																		✓		✓
	S4																			✓	
	S6																				
	S14																			✓	✓

Sports Engineering

		BEng																									
	Modules	Year 1							Year 2						Year 3								Year 4				
		56101	56103	56105	SS241	HP102	HP107	HP109	56201	56206	56207	HP110	HP111	HP202	56301	56302	56311	56316	56317	12379	HP306	HP417	56409	56418	56424	HP317	HP416
Output Standards	Underpinning Science & mathematics																										
	US3	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓
	Engineering Analysis																										
	E2														✓	✓											
	E4			✓					✓		✓				✓		✓		✓				✓				
	Design																										
	D5	✓							✓								✓		✓				✓	✓	✓		
	Engineering practice																										
	P3														✓				✓					✓	✓		
	General Learning Outcomes																										
	G3			✓							✓					✓											
	G4	✓								✓																	

Figure 4. DMEM Course ISD analysis

Analysis of the engineering courses offered by the DMEM department (figure 4) highlights that learning objectives (LO) derived from the Engineering Council's UK-SPEC accreditation [28] are present across the undergraduate programmes of study. However, what is evident from the analysis is that only a handful of these learning objectives are integrated within current course modules and thus the student's exposure to systems integrations and systems engineering principles are limited. In this particular case study the adoption of the analysis method has provided two key elements of information: 1) Integrated Systems Design principles are present in modules offered to DMEM students from the first year of their undergraduate degree through to their final year, 2) There is scope for developing a set of core integrated systems design modules which are interchangeable across the courses offered in the department. In the case of DMEM, this extends beyond the departmental boundaries. Initial analysis on other departments in the engineering faculty has shown that they too may have similar ISD principles integrated within their core modules. This has led to the hypothesis that there may be sufficient scope for developing dedicated ISD modules which would be made available at the faculty level, incorporating the three disciplines of Design, Electrical and Mechanical engineering with the core principles of systems integration.

Although conducted within only one department and within one university, the case study presented in this paper may be indicative of other departments within the University of Strathclyde and possibly a number of universities across the UK. The perception gained from the case study is that the issue is not that ISD is a subject too complex to be taught at undergraduate level, but rather that the principles are already being taught, they are just not explicitly communicated as such and it is this which should be addressed.

6. CONCLUSIONS / DISCUSSION

This paper presented the following hypothesis: if engineering students were provided with systems thinking principles and experience at the undergraduate stage in their academic studies then you will provide organisations with graduates able to contribute to the business with more immediate impact.

Literature evidence suggests that the principles of systems integration are too complex a subject to be taught at the required detail in school education and at undergraduate level most engineering courses focus on single disciplines [14]. Traditionally, engineers encounter the need for systems integration when working in industry [25]. Given the duration of large-scale projects, and the need to accrue the necessary experience and knowledge to become a successful systems engineer, the process of gaining the appropriate skill-sets through the traditional experiential route is a long process. Discussions with industry confirm this process is too long and inappropriate for today’s markets.

A review of the Universities & Colleges Admissions Service (UCAS) and ‘Prospects’, the graduate course listing website, tells us that of the UK based courses specifically focused on systems engineering and integration, only a few are taught at undergraduate level whilst most are at postgraduate level. Many of these postgraduate courses are born from industrial needs and as such are often designed for specific sectors of industry such as energy, defence, aerospace or marine. Undergraduate programmes world-wide offering systems integration teaching often use a project based approach, [13, 15-16]. Discussions with industry colleagues confirm a preference for this type of approach and a belief that industry focussed projects is preferable to ‘university in house projects’. Although there was also general agreement such projects are often more difficult to develop and monitor.

However, the research undertaken within this project has shown that although these perceptions of ISD principles being too complex for undergraduate study are widely accepted, the reality is different. Through the use of an analysis matrix developed using the Engineering Council’s higher education learning objectives as the prime metric, we have presented a case study which we believe to be indicative of most UK based universities offering engineering courses at undergraduate level. The case study has shown that by adopting the UK-SPEC LO, universities are tacitly integrating the principles of systems engineering and integrated systems design into their course modules.

7. FUTURE STEPS / WORK

At this stage we believe that the project is on target to achieve the goal of demonstrating to academics and industrialists the importance of teaching integrated system design during undergraduate studies. The case studies undertaken within the University of Strathclyde has shown potential to develop multi-department teaching modules for students (where possible in conjunction with industry), and ensure students who graduate from the university are equipped with the skills required by industry. This process is very much in line with the University's excellence agenda to develop world class graduates who are attractive and useful to industry. To develop this project further and ensure that the principles of ISD are recognised across the UK and potentially worldwide, this project aims to engage closely with other academic institutes and accreditation bodies. In particular the authors intend to engage with other RAEng Visiting Professors to provide analysis and evaluation of ISD principles within current course offerings. The intention for this work is to ensure that the UK and international engineering industry actively choose to recruit graduates from universities which embrace a systems thinking approach to engineering design and development. And as a consequence these universities gain worldwide notoriety for producing graduates with enhanced skill sets.

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