Development of Mechatronic Engineering Course for a Military Technological College in Gulf Region

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Abstract: Curriculum development, renewal and innovation are critical to successful engineering programs. In this paper, the authors describe the development of a new mechatronic engineering program at a new college of Higher Education. Small class sizes and high staff-student ratio are among the distinguishing characteristics of the college.

The development of a mechatronic degree was taken to ensure that it meets the requirements of the Ministry of Defence Engineering Services. It has been both innovative and strategically designed in terms of balancing between the technical competencies required and the academic rigor of the 21st century engineering programs meeting international standards. The resulting program curriculum is thus both flexible and relevant. The flexibility of design of the Systems Engineering programs allows the pursuit of a variety of pathways. In addition, the curriculum is relevant as it is structured to allow for emphasis areas, aligned with stakeholders' requirements, ensuring fit for purpose knowledge and minimizing the period of the on job training. The paper discusses the resulting implementation of the course and highlights the analysis and mapping against the expected profile of the graduates.

Key-Words: mechatronics, skills-set, multidisciplinary engineering, training needs analysis, learning outcomes, engineering education, fuzzy classification.

1 Introduction

1.1 Background – what is Mechatronics?

Mechatronics, as one of the new engineering disciplines, has been established for some time now. Initially, Mechatronics was thought of as a combination of mechanical and electrical/electronic skills. The need for mechatronics specialists had arisen as a result of progress with industrial technologies, for instance robotics and automation of production. In those areas engineers had been working with devices containing both mechanical and electrical parts and needed knowledge of both components. As technology progressed further, additional aspects were emerging, including computer software, embedded computer systems, control systems technology, instrumentation, sensors and actuators. The Mechatronics journal of IFAC (the International Federation of Automatic Control), provides the following definition of how Mechatronics is understood today: "*it is the synergistic combination of precision* ***mechanical engineering****,* ***electronic control*** *and* ***systems thinking*** *in the design of products and manufacturing processes. It relates to the design of systems, devices and products aimed at achieving an optimal balance between basic mechanical structure and its overall control. […]. It will cover a wide range of application areas including consumer product design, instrumentation, manufacturing methods, computer integration and process and device control, […]. A major item will be the design of machines, devices and systems possessing a degree of computer based intelligence.* "

As seen from the above definition, Mechatronics spans a wide range of application areas. All products, devices and processes which contain mechanical (moving) subsystems, supported by electronic instrumentation and embedded computing (intelligence) can be considered as mechatronic systems. Traditionally, mechatronics was associated with robots. These days it is not limited to robots but also includes, for instance, automotive vehicles (currently an average passenger car is equipped with a number of sophisticated sensors, microcomputers and thousands of lines of software code running all the time when the vehicle runs), consumer devices such as washing machines, tracking and pointing devices (e.g., CD readers, radars, surveillance systems) intelligent medical or rehabilitation devices (e.g. wheelchairs, intelligent prosthetics, scanners), chemical processes which require moving parts, e.g. stirring separation, printers and 3D printers, CNC machines, and many more [6].

The needs and requirements of mechatronics education have been discussed in several publications. In [1] an early overview is provided with a reference to a typical mechatronics engineering programme at that time. The Authors rightly concluded that there would be an increasing demand for mechatronics graduates in the future. In [2] the Author shares experience of developing mechatronics course for mechanical engineering students. Similar theme, but for a different educational environment is presented in [8]. [10] discuss how mechatronics as academic subject is evolving in terms of identity and legitimacy. This is supported by examples from universities in northern Europe. More recent reflection on development and running of mechatronics course over the 10 years period is given in [15]. Furthermore, the Authors mention the impact of mechatronics curriculum in the light of changes of global economy.

[11] present development of mechatronics curriculum in Jordan, being one of first such courses in the Middle East region. They emphasise the difficulties related to lack of research funding in this field and hence conclude that strong links to local industry are needed to ensure the course relevance to regional needs.

[9] points out to a need of a balance between depth and breadth in education of mechatronics, and that students should be exposed to practical aspects of systems' integration. [13] emphasises in mechatronics the synergy between knowledge, practices and professional skills. The efficient mechatronics education, according to this author, should be based of interdisciplinarity and on project and problem based learning, both individual and group.

[4] consider mechatronics to be a good example of interdisciplinary engineering. Hence, they discuss how involvements with it opens up new perspectives in terms of research topics and research directions. On the other hand, [14] argue that mechatronics is a good vehicle to promote engineering and engineering education, for instance to students in secondary education, because of its interdisciplinarity and because project based learning can be naturally incorporated in it.

It is important in studying mechatronics that students work in interdisciplinary teams in order to efficiently design and maintain the systems [6]. This is one of the recognised core aspects of modern engineering practice [20] which is naturally reinforced in this pathway of study. Several publications report development of project based learning and problem based learning, for instance based on robots: [17] and [18], or robotic vehicles: [19], [16].

The Mechatronic pathway, similar to other engineering pathways in the College is based on five specific building blocks. These building blocks are 1) problem-centered learning 2) upside down curriculum 3) mathematics in context 4) design orientation and 5) appropriate balance between simulation and laboratory work. These are all connected with the central theme of sustainability, transferable skills, safety and entrepreneurship.

1.2 Specific requirements of military education

The military technical college (MTC) considered in this paper offers a suite of programmes to satisfy the needs of the Armed Forces of the country and the needs of the nation from both a technical and academic standpoint. Whereas "traditional" university programmes mainly focus on academic output, MTC have to integrate the academic output with the engineering requirements of Armed Forces, called the Training Need Analysis (TNA) requirements. The College offers courses in four academic departments, namely: Aeronautical Engineering, Civil Engineering and Quantity Surveying, Marine Engineering and Systems Engineering. In the Department of Systems Engineering one of specialisations/pathways is Mechatronic Engineering. Many of the application areas of Mechatronics, as listed above have potential for being useful to military personnel.

Mechatronics as a military direction of study is not unique to MTC. For instance, Military Technical Academy (WAT) in Warsaw, Poland has a Faculty of Mechatronic and Aviation Engineering which offers degrees in Mechatronics, Aviation and Aerospace, and in Safety Engineering. The degree in Mechatronics is further divided into specialisations: Control and Automation, Computer Systems in Mechatronics, Applied Mechatronics, Weapons and Ammunition, Anti-Aircraft Missiles, Radio electronics, Electronic Weapon Systems [23].

In meeting the requirements of this college, the Mechatronics specialisation stems from the part of the Forces responsible for engineering services. Hence, the main areas of applications will not be in issues related to combat itself, but in the services needed for providing the infrastructure for logistical operations of Armed Forces. By way of example, mechatronics engineers and technicians will find employment in water treatment and water de-salination plants, in power generation installations, in maintenance and installation of ventilation systems, in ground radar/communication systems, and in specialised vehicle maintenance facilities. Furthermore, looking to future development of Armed Forces, there will be increasing demand for specialisations related to unmanned vehicles, robotics, medical and mechatronic devices.

1.3 Entry and exit points

Students apply and are admitted to the college through the universities and colleges admission system, common to all higher education institutions in the country. Additional requirements relate to the fact that the students, at the time of admission are also enlisted to the Armed Forces. The College has adopted the British education system. Indeed, the programmes of study have been validated by a British University and the degrees awarded are equivalent to British degrees. The students in MTC enrol on the programme consisting of: one year preparatory study, titled the General Foundation Programme, which is aimed at closing the gap between the exit qualifications of the secondary school system in the country of the College and those in the UK. This is then followed by the engineering programme which comprises one year of Engineering Foundation (UK Level 3), followed by two further years leading to Diploma in Higher Education (Levels 4, 5) and one further year to complete Bachelors (honours) degree in Engineering (Level 6, BEng).

It is also planned to further extend education options by offering taught Master programmes and research based PhD programmes.

The majority of students in the first instance will complete their course of studies and exit the college upon graduation at level 5, the Diploma in Higher Education. When exiting at this point, it is an essential requirement that students are prepared to serve and to immediately contribute to the appropriate engineering division of the Armed Forces.

2 Development of the course

2.1 Structure of the course – academic contents and practical skills

The course structure was developed taking into consideration two important criteria: i) that the course be internationally recognised and satisfy the requirements of a mechatronic degree, thus equipping graduates for employment in areas of industry which broadly embrace the discipline of mechatronic engineering; ii) secondly, to meet the specific requirements of the engineering services of Armed Forces with respect of deployment of mechatronic engineers and technicians, both in the immediate and longer-term future. The full body of knowledge and skills delivered to the students consists of their “academic modules” plus the skills based “non-academic” modules, affording them practical experience with mechatronic devices in military service contexts.

2.1.1 Academic Modules

The academic modules address all aspects relating to the Mechatronic pathway specialisation. The programme design is as follows:

- An engineering foundation programme provides background knowledge and skills in engineering science (MTCS3002), engineering mathematics (MTCA3001), electrical engineering (MTCM3004) and engineering design (MTCS3007).
- An engineering design stream is present in all years of study, culminating in individual projects at Level 6 (BEng honours).
- Students acquire extensive knowledge in electronics, commencing at Level 4 (electronic fundamentals (MTCA4008) and analogue and digital electronics (MTCS4009)), continuing at Level 5 with power electronics (MTCS5024), and at level 6 with embedded computer systems (MTCS6013).
- Control and Signal Processing is covered by two modules at Level 5 (instrumentation and control (MTCS5005) and control systems and design (MTCM5034), and two modules at Level 6 (digital signal processing (MTCS6017) and embedded computer systems (MTCS6013)).
- Data Communication plays an increasingly important role in Mechatronic devices. This module is delivered at Level 4 (MTCS4010).

- Students are exposed to Mechanical Systems, commencing with a module at Level 4 (MTCM4007), followed by the module engine and transmission systems (MTCS5002) at Level 5 and by power systems and design (MTCM6033) at Level 6.
- Fluid Systems (MTCM5025) is delivered at Level 5. This affords students the necessary understanding of hydraulic actuation and wider mechanical fluid processes which they will encounter in the future workplace assignments.
- Students acquire professional development and practice skills via modules including: safety engineering and risk management (MTCS5001), and engineering management (MTCM6006).

2.1.2 Acquiring additional practical skills

Student practical skills are developed through their workshop activities which enables them test in practice the knowledge gained in their academic modules of study. Those workshops extend and complement the academic delivery.

The college Training Needs Analysis (TNA) requirements lists competencies which students must acquire in readiness for practice in the Mechatronics trade. These competencies include the following:

MD71: Participation in electronics and communications work through competency development activities

MD74: Writing specifications for industrial electronics and control projects

MD179: Welding using gas the metal arc welding process

MD186: Monitoring and control of power generation systems

MD600: Maintaining and repairing mechanical drives and mechanical transmission assemblies

MD607: Inspecting and repairing faults in mechanical equipment components

MD611: Maintaining hydraulic systems

MD622: Conducting technical inspection of process plant and equipment

MD623: Conducting performance testing on process plant and equipment

MD628: Arranging circuits, with control and protection for general electrical installations

MD636: Developing and connecting electrical control circuits

MD641: Installing and maintaining emergency safety systems

MD651: Operating and maintaining waste water treatment plant and equipment

MD652: Operating and maintaining water desalination plant and equipment

MD704: Removing, install, operating and troubleshooting computer software and hardware systems

MD705: Conducting quality and functional tests on assembled electronic apparatus

MD706: Designing electronic control systems

MD707: Providing solutions for embedded electronic control systems

MTC 101B: Interpreting occupational health and safety maintenance practices

MTC 103B: Planning and organising maintenance related work activities

MTC 105C: Applying quality standards applicable to maintenance processes

MTC 107B: Interpreting and using maintenance manuals and specifications

MTC 108B: Completing maintenance documentation

MTC 109: Performing basic hand skills, standard trade practices and fundamentals in maintenance

MTC 112B: Planning and implementing maintenance activities

MTC 113C: Supervising maintenance activities and managing human resources in the workplace

MTC 118A: Conducting self in a maintenance environment

Note: that the competencies coded MTC are generic in nature, they apply to withal graduate Diploma of Higher Education modules, not only those with specialisation in Mechatronics.

In a vocational education setting, each competency will be taught by a combination of theory and practice over a period of several weeks. The approach taken at MTC, in delivery of competencies is split between academic modules and workshop skills. Academic modules cater for most of the required underpinning theory. Additional theoretical elements are added to enhance workshop activities as required. Practical hands skills are also partially acquired via completion of the academic module laboratory practicals. This has been possible owing to well-equipped laboratory facilities. Ninety percent of academic modules taught at MTC have scheduled laboratory/engineering practice sessions. Nevertheless, there is a relatively large proportion of hands skills, which are related to particular types of military equipment and therefore cannot be covered through academic module delivery. To accommodate these additional requirements, practical workshop hours have been scheduled as an important and integral part of the programmes of study at MTC.

2.2 Meeting Engineering Council UK SPEC Learning Outcomes

Accreditation of an engineering degree programme is an important mark of assurance that the programmes of MTC will meet the highest standards set by the engineering profession. MTC programmes are designed to satisfy the standards of the discipline specific Professional Engineering Institutions, enabling graduates to become professionally recognised Chartered (CEng) or Incorporated (IEng) engineers, as defined by the United Kingdom Standard for Professional Engineering Competence [21]. The Institute of Mechanical Engineers (IMechE) has been selected as the appropriate engineering institution to accredit the Mechatronics pathway.

UK-SPEC requires achievement of five *Specific learning outcomes* and *four General learning outcomes*.

The General Learning Outcomes (GT) cover, in summary, specific areas of personal development and transferrable skills.

The specific learning outcomes, are briefly summarised herein:

Science and Mathematics (SM): to provide underpinning of scientific principles necessary for the students' engineering discipline. For the Mechatronics pathway, this spans a wide range of areas of physics, to underpin understanding of electronic devices, mechanical systems, electric motors, hydraulic systems, thermal systems, and more. Mathematics in context is extensively required, not least for control theory, signal processing, and data transmission systems.

Engineering Analysis (E): Underpins required knowledge to apply engineering principles, quantitative and computational methods to the solution of engineering problems. The emphasis is on a *System-based approach to defining and analysing problems.* As Mechatronics is concerned with systems, and 'systems of systems', students must be equipped with very sound skills in engineering analysis. Exposure to engineering software design packages play an important assistive role herein.

Design (D): Instilling capability in design is a vital requirement when developing an engineering degree. In the study of Mechatronics, a very important factor is that of interdisciplinary, with necessity to merge components and sub-systems from mechanical, electrical, electronic, and software engineering domains.

Economic, legal, social, ethical and environmental context (S): it is necessary that engineering graduates be aware of environmental and societal impacts that engineering activities may impose, and be able to manage those impacts accordingly.

Engineering practice (P): For the purpose of accreditation, it is required that students encounter elements of practical engineering whilst completing their programme of study. At MTC, this requirement is taken to an advanced stage owing to integration of the academic modules with TNA delivery. In particular, the Mechatronics course is designed in such a way that students are exposed to practical devices ranging from electric motors, gearboxes and power transmission systems, electronic circuits, process control equipment, and more.

3 Course Implementation

3.1 Delivery of academic contents.

MTC has opted for an innovative course design which aims to equip students not only with sound engineering knowledge but also with the ability to solve problems and the ability to plan their personal development, thus enabling readiness for future progress in technology [5], [7].

The core building blocks of the MTC programme are in:

- Project based learning, where ill-defined projects stimulate students' creativity and teach them that there may be multiple solutions to one problem.
- Science and Mathematics taught in the context of engineering applications. This allows bringing-in practical problems at early stages of study, so that mathematical and scientific principles are learned while being applied to those problems, hence motivating students and maintaining their interest in the chosen direction of study.

- Emphasis on development of practical skills as well as skills in simulation. For that purpose, the students are exposed to laboratory/workshop activities in almost all modules taught at MTC.
- Strong design orientation, with Engineering Design being taught as dedicated modules and also as mini-design-projects in many specialist modules.
- Exposing students to interdisciplinary between their specific course and other engineering courses.

Mechatronics, as one of courses offered by MTC shares the aforementioned principles. For Mechatronics they are perhaps even more important than for others, because it is a rapidly changing and evolving discipline. Students must be able to follow the technology and move across boundaries of engineering specialisations.

Table 1 shows the structure of the course and how it meets the requirements for professional accreditation.

3.2 Delivery of practical skills training

The design of the Mechatronics course has been based on a holistic approach where both the academic contents and the practical (skills related) contents have been considered jointly to enable best fit in all modules. However, owing to specific military requirements, the extent of practical skills exceeds those normally associated with accredited engineering degrees. Some of those practical skills are difficult to justify as part of an engineering programme of study. Moreover, some of them are related solely to military requirements. As MTC may in the future also offer civilian degrees, it seemed appropriate to separate the purely practical and purely non-academic contents of the competencies into modules (units of study) which do not necessarily contribute to the degree classification. Hence, the competency related modules are delivered in addition to the academic modules.

In the Mechatronics degree, additional (non-academic) training amounts approximately to five hours per week (180 hours per year). In accordance with the European Credits System (ECTS), a university level degree should amount to between 1500 to 1800 hours of study per academic year. From these hours a proportion only is devoted to contact hours and a further portion to directed self-study. Students are provided reference material and are asked to perform projects, tasks, and additional study outside the classroom. The percentage of contact hours varies, depending on the University and the course of studies. For example, at WAT (referred to earlier) the proportion is approximately 50% for a Mechatronics degree. At MTC, not taking into account the additional (non-academic) modules, the percentage of contact hours is approximately 32%. With the non-academic modules added on, this increases to 44%. Hence, the overall load on students remains within the European standards. Moreover, it can be argued that those additional, practical classes improve students' ability to learn academic modules, giving them immediate practical experience of the theories learned during the lectures. It also supports the MTC concept of engaging students in practical activities and giving them exposure to their selected field of engineering from the outset.

The additional (non-academic modules for the Mechatronics pathway are as follows:

Level 3: General Hands Skills, General Automotive Skills, General Electrical Skills.
These modules train students towards gaining knowledge and achieving compliance with the requisite general competencies. These competencies are briefly introduced at level 3 and are followed up later (at levels 4 and 5) with context to particular engineering exercises.

Level 4:
The General Systems Engineering Skills module provides further contribution to "general competencies. It is followed by two modules which are aimed at particular skills required for Mechatronics technicians. The approach used when meeting the training needs in this particular course is that each competency is developed slowly, over a longer period of time, in some cases over the whole duration of study. Students are exposed to exercises wherein complexity increases over time, commencing with identification of systems, becoming familiar with normal operation, practicing assembly and disassembly, and culminating in acquiring relatively advanced maintenance and troubleshooting competencies. Hence, from the second Trimester at Level 4, students will start working towards all competencies, from MD186 to MD706.

Level 5: at level 5 students continue in advancing all competencies, but emphasis is now shifting towards advanced maintenance and troubleshooting. MD707 is introduced at this level, because it requires a theoretical knowledge which had not been available earlier.

Students finish all the non-academic modules by the end of Level 5. Hence those who exit with Diploma, i.e. after Level 5, will be fully qualified to take-up duties in their workplace.

It also has to be highlighted that the academic modules play a very important role in fulfilling the non-academic training needs. This is owing to two facts:

1. Academic modules provide theoretical background, which is **highly relevant** to practical competencies. Therefore, those practical competencies can be acquired easier and with better understanding.
2. Academic modules themselves contain a substantial amount of workshop/laboratory exercises, to the extent that some of the non-academic competencies are fully covered by them. For instance, MD71: Participate in electronics and communications work and competency development activities, and MD74: Write specifications for industrial electronics and control projects, are extensively covered, starting from Level 4 with the modules: Analogue and Digital Electronics, and Electronic Fundamentals, and in the modules Engineering Systems Design 1 and 2.

Further to point 2: it may be possible to examine students' attainment of TNA skills/competencies during the performance of academic modules. However, this approach is not implemented at present. With respect to point 1: it can be observed that the background academic knowledge is very helpful, in terms of quality and in speed of learning – for the practical skills. However, this is difficult to measure. Hence, when assessing the contribution made by academic modules to the non-academic competencies, it is necessary to adopt a certain level of subjectivity. As a possible method, suitable to providing a numerical representation, a fuzzy classification [3], [12] has been adopted herein. In this approach, each of the 27 competencies has a set associated with it. For each of the academic modules a fuzzy set membership function is determined for each of the sets representing competencies. The value of the membership function is between 0 and 1. It is assigned subjectively, based on the inspection of the contents and delivery plan of the module, gauged to the "required skills and knowledge" of a given competency. It is considered whether the activities of the module contribute directly to the required skills and whether they provide useful background knowledge. Both are merged together as one fuzzy membership number. The results of this analysis is shown in Table 2. Additionally, the last column in Table 2 provides the assessment (also to some extent subjective) on the extent to which a given competency is covered in all academic modules. This is not necessarily a simple sum of coverage in all individual modules because there may be overlaps between modules and some parts of a competency may remain not-covered.

An analysis of the results in Table 2 demonstrates that: 7 from the total 27 competencies are not covered at all, however 7 competencies are covered in at least 50% of their contents. Taking all 27 competencies, on average, 1.59 modules contribute towards one competency. Taking all 18 modules, on average 2.39 competencies are being partially addressed per module.

This analysis illustrates that the academic training plays an important role in helping to develop practical competencies and skills. It is also interesting to analyse the reverse, i.e. how the practical training contributes to attainment in development of academic skills.

For that, we propose to consider the expected profile of a graduate of the Mechatronics degree programme. As stated earlier, Mechatronics can be seen as a combination of four main engineering disciplines:

- Mechanical Engineering
- Electrical/electronic Engineering
- Software Engineering
- Control Engineering

Most of the academic modules and also non-academic (skills related) modules, contribute to one or more of the four disciplines. For instance, the module: Electrical Engineering Principles contributes substantially to the electrical/electronic discipline; the module Engineering Mathematics 1 contributes by a small amount to the discipline "Software Engineering" by reinforcing the knowledge of mathematical logic; the module Engineering Mathematics 2 contributes to: "Software Engineering" – elements of programming are introduced in a context of specialised software, but it also contributes to "Control Engineering", because it introduces the concepts of transformation of signals to the frequency domain. This level of contribution, for each of the modules, to each of the four disciplines is assessed (subjectively) with a value between zero and one, representing a fuzzy membership.

For Mechatronics Engineers it is important to work on the boundaries of disciplines, be able to transfer knowledge/experience from one discipline to another and be able to apply a system based approach to systems consisting of sub-systems from different disciplines. As a possible measure of preparedness to this aspect of work, consideration may be given to the coverage of cross disciplinary issues, involving pairs of the four main disciplines defined above. These pairs, for the purpose of this study have been proposed as:

- Mechanical Computer Aided Design (Mechanical - Software)
- Electro-mechanical systems
- Control electronics
- Embedded control systems (Control - Software)
- Control of machines and processes (Control - Mechanical)
- Modelling and simulation (Electronics - Software)

Similarly to the approach described above, fuzzy classification of the modules to each of the above six cross-disciplines has been determined.

Finally, the areas of applications of mechatronics is continuously expanding. The graduates should be prepared for the challenges of the job immediately following completion of their study, but should also be ready for the more distant future. Possible industrial areas wherein Mechatronics has a significant position now, or is likely to have in the future are:

- Consumer products
- Manufacturing and robotics
- Medical devices
- Process control
- Copying, printing, positioning
- Instrumentation and actuation
- Vehicles (land, sea, water)
- Energy generation and storage

This is by no means exhaustive. It serves here only for the purpose of illustration. In the same fashion as above, fuzzy classification has been performed for each of the modules as "belonging" to a given industrial application area.

The results of the three above classifications are presented together in Table 3.

Furthermore, the analysis of contribution of the whole course (all modules) has been performed, for each: discipline, cross-discipline and application area. To obtain this, the sum of "memberships" of individual modules has been calculated. This can be interpreted as a measure of strength (power) of representation of each of the disciplines, cross-disciplines and application areas in the course. The results are presented in Figures 1, 2, and 3. A noticeable feature is that practical training does contribute to academic qualification training. For instance, in Mechanical Engineering, this contribution is approximately 45%, with similar results for Control of Machines and Processes.

Overall, the course places the highest emphasis on Mechanical Engineering whereas if looking at the academic modules only, the highest contribution is towards electrical/electronic Engineering. This is justified by the fact that many practical mechanical skills are required of the graduates and those are appropriate to be delivered in non-academic modules, whereas, when it comes to Electrical/electronic skills, those are largely covered by academic modules.

Considering the cross-disciplinary aspects, a combination of control and software is very strongly represented. This compensates the fact that the software itself is the least represented of the four areas, both on the academic side and on the practical side. The nature of the modules is such that they are more likely to be (fuzzy) classified as "software application" than pure "software engineering". This is appropriate for this particular course which is highly practical in nature.

The application areas which have emerged highest resulting this study are: Instrumentation and actuation, process control and Energy generation and storage. This has confirmed that the course design was suitable for the needs of Armed Forces with the demand for qualified mechatronics engineers, precisely in those three areas. However, looking more to the future, the course also enables students' good exposure to areas such as: robotics, medical devices and vehicles. Consumer products, copying printing, positioning is less represented. This again appears to be appropriate, taking into account the desired profile of the graduate.

3.3 Use of workshop and laboratory equipment to support academic delivery and non-academic skills.

To illustrate the inter-relation between academic modules and non-academic skills, we consider one particular set of equipment available in student training –the Process Control Laboratory. This laboratory contains tanks, piping, vessels, supported by instrumentation and control systems (Programmable Logic Controllers).

It is used in the course of academic training, namely in the modules relater to Control and Instrumentation Engineering, and in the delivery of trade skills, namely those related to technical inspection and performance testing of process plant and equipment.

The students are first introduced to this laboratory in Level 4, as part of their non-academic skills training. At this stage, the objective, which is set-up in accordance with the definition of the skills set, is to acquire knowledge of:

- Relevant Environmental, Occupational Health and Safety regulations.
- Ability and understanding in technical drawings and manufacturers manuals
- Typical arrangements of process plant
- Plant operating parameters
- Environmental awareness
- Relevant test equipment
- Data logging systems
- Engineering assembly, design and operating principles

The goal is achieved by a series of practical exercises wherein the student will:

- Connect, disconnect vessels and pipes,
- Build a plant configuration according to the schematic diagrams provided,
- Connect instruments (flow, level, temperature sensors),
- Connect a data logging system,
- Connect a closed-loop controller, run the plant, monitor its operation and identify problems.

Next, the students are exposed to the same training set in Level 5. This is then part of their academic module: Instrumentation and Control. The exercises performed will contribute to the learning outcomes of this module, hence enabling students to:

- Describe the types and operation principles of various instruments, transducers and sensors in automatic control systems.
- Explain the Laplace transform as a standard technique to represent a system with a single transfer function.
- Describe how automatic control system can be represented with block diagrams, - transfer functions, time responses, and feedback closed loops indicating the signal flows of the actual system.
- Examine different types of control systems and analyse performance characteristics of PID automatic control systems widely used in industrial control systems.
- Provide examples of the use of digital controllers in an industry standard implementation of an automatic control system.

The tasks which the students are required to perform include:

- Describing mathematically the dynamics of the system
- Analysing the system responses to disturbances and set-point changes
- Designing and implementing a controller to meet given performance specifications
- Observing and analysing the system's operation for selected scenarios

At the same time, as well as contributing to the academic learning outcomes, the exercises performed enable the students to progress with their practical, non-academic skills. Firstly, all the skills acquired in the previous year are enhanced, secondly, new skills are acquired, such as, to acquire knowledge of:

- Plant operating parameters.
- Inspection and test procedures.
- Diagnostic techniques.
- Data analysis techniques and tools.
- Plant performance assessment and calculation.

Finally, students return to the same equipment set in Level 5, in their non-academic training. This time the emphasis is on performance assessment, application of diagnostic techniques, fault finding and troubleshooting.

It is worth noting that, in the example provided, students are commencing their exercises, practical contacts with Control Engineering before they are given a theoretical background to it. This follows the principle of Mathematics and Science taught "in context". When the theory of Control Systems is introduced in Level 5, students are able to relate it to the practice of those process plants, which they observed earlier. This concept, sometimes, is also referred to as "upside-down curriculum".

4 Conclusion

The paper outlines design and implementation of a Mechatronics Engineering course, for the needs of military education in a country in the Gulf Region.

The course caters for the specialisations related to Armed Forces engineering services, rather than those related to combat itself.

It is designed to meet the requirements of ECUK accreditation, at the same time providing graduates who can potentially exit at the Diploma level with the set of practical skills suitable for their service in the Armed Forces.

The structure of the course has been analysed, from the perspective of accommodating major engineering disciplines and cross-disciplinary factors. Also, the extent to which different application areas associated with mechatronic systems are covered has been measured. This shows that the course implementation meets the initial design criteria. The methods of analysis presented in this paper can be useful in the future possible re-designs/re-adjustments of the course to adopt to changes in technology and in market demand.

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5 Appendix: Tables and Figures

Programme Title:	Level 3						Level 4						Level 5						Level 6				
	Module numbers (where the output criteria statements are addressed)																						
BEng Degree in Systems Engineering, pathway: Mechatronic Systems	Engineering Mathematics 1 (MTCA3001)	Engineering Science (MTCS3002)	Electrical Engineering Principles (MTCM3004)	Engineering Materials and Hardware (MTCA3003)	Engineering Systems Design 1 (MTCS3007)	Introduction to Electrical Engineering (MTCM3005)	Engineering Mathematics 2 (MTCA4001)	Engineering Systems Design 2 (MTCC4002)	Electronic Fundamentals (MTCA 4008)	Analogue and Digital Electronics (MTCS4009)	Data Communications (MTCS4010)	Mechanical Systems (MTCM4007)	Safety Engineering & Risk Management (MTCS5001)	Instrumentation and Control (MTCS5005)	Power Electronics (MTCS5024)	Fluid Systems (MTCM5025)	Control Systems and Design (MTCM5034)	Engine and Transmission Systems (MTCS5002)	Engineering Management (MTCM6006)	Power Systems and Design (MTCM6033)	Digital Signal Processing (MTCS6017)	Embedded Computer Systems (MTCS6013)	Individual Project (MTCA6001)
Examination	70%	50%	60%	60%	0%	60%	60%	0%	60%	50%	70%	70%	60%	60%	75%	70%	70%	60%	50%	70%	50%	60%	0%
Coursework	30%	50%	40%	40%	100%	40%	40%	100%	40%	50%	30%	30%	40%	40%	25%	30%	30%	40%	50%	30%	50%	40%	100%
Compulsory or optional module	C	C	C	C	C	C	C	C	O	O	O	O	C	O	O	O	O	O	C	O	O	O	C
Science and Mathematics																							
SM1		✔	✔	✔		✔	✔		✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
SM2	✔		✔	✔		✔	✔			✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	
SM3																					✔	✔	✔
Engineering Analysis																							
E1		✔	✔	✔	✔	✔				✔	✔		✔	✔	✔	✔	✔	✔		✔	✔	✔	
E2					✔		✔		✔					✔			✔		✔	✔			✔
E3	✔	✔	✔	✔	✔	✔	✔					✔				✔	✔	✔	✔	✔			✔
E4								✔						✔		✔			✔	✔			
Design																							
D1					✔			✔								✔			✔				✔
D2	✔				✔		✔	✔		✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
D3					✔			✔						✔					✔				✔
D4					✔			✔				✔		✔			✔		✔	✔	✔	✔	
D5					✔			✔											✔		✔	✔	
D6					✔			✔											✔				✔
Economic, legal, social, ethical & environmental context																							
S1				✔	✔			✔											✔				✔
S2				✔	✔			✔						✔					✔				
S3					✔			✔						✔					✔				
S4				✔	✔			✔											✔				
S5				✔				✔		✔	✔		✔		✔				✔	✔			✔
S6		✔			✔	✔		✔				✔	✔		✔	✔			✔	✔			✔
Engineering Practice																							
P1					✔							✔						✔	✔				
P2		✔	✔	✔	✔	✔		✔	✔	✔	✔		✔	✔	✔	✔	✔		✔	✔	✔	✔	
P3		✔	✔	✔		✔			✔	✔	✔	✔	✔	✔	✔	✔	✔	✔		✔	✔	✔	
P4				✔				✔				✔				✔	✔	✔	✔	✔			✔
P5				✔						✔	✔		✔	✔	✔	✔			✔				
P6																			✔	✔	✔	✔	
P7																			✔				
P8																			✔				✔
P10					✔	✔		✔	✔		✔		✔	✔	✔	✔							
P11																			✔	✔	✔		
Additonal General Skills																							
GT1					✔		✔	✔					✔			✔	✔		✔				✔
GT2					✔			✔											✔				✔
GT3					✔			✔					✔										✔
GT4					✔			✔											✔				✔

Table 1. Output Standards Matrix for Mechatronics course.

Programme Title:	Level 3						Level 4						Level 5						TOTAL
	Module names and numbers (where the output criteria statements are addressed)																		
Diploma Degree in Systems Engineering, pathway: Mechatronic Systems	Engineering Mathematics 1 (MTCA3001)	Engineering Science (MTCS3002)	Electrical Engineering Principles (MTCM3004)	Engineering Materials and Hardware (MTCA3003)	Engineering Systems Design 1 (MTCS3007)	Introduction to Electrical Engineering (MTCM3005)	Engineering Mathematics 2 (MTCA4001)	Engineering Systems Design 2 (MTCC4002)	Electronic Fundamentals (MTCA 4008)	Analogue and Digital Electronics (MTCS4009)	Data Communications (MTCS4010)	Mechanical Systems (MTCM4007)	Safety Engineering & Risk Management (MTCS5001)	Instrumentation and Control (MTCS5005)	Power Electronics (MTCS5024)	Fluid Systems (MTCM5025)	Control Systems and Design (MTCM5034)	Engine and Transmission Systems (MTCS5002)	To what extent covered in all modules
Specific competencies for Mechatronics trade																			
MD71:									0.5	0.5	0.5			0.1					0.95
MD74:								0.3		0.5				0.5			0.5		0.75
MD179:																			0.00
MD186:						0.1									0.1				0.10
MD600:												0.2						0.5	0.60
MD607:																		0.3	0.30
MD611:																0.4			0.40
MD622:														0.3					0.30
MD623:														0.1			0.1		0.10
MD628:			0.2			0.5									0.1				0.50
MD636:																			0.00
MD641:																			0.00
MD651:																0.2			0.20
MD652:																0.2			0.20
MD704:																			0.00
MD705:									0.4	0.3									0.40
MD706:														0.3			0.4		0.60
MD707:																	0.2		0.20
Additonal General Competencies																			
MTC 101B:		0.1	0.1	0.1	0.1	0.1		0.5	0.1	0.1		0.1	0.9					0.1	1.00
MTC 103B:													0.4						0.40
MTC 105C:													0.4						0.40
MTC 107B:								0.2											0.20
MTC 108B:																			0.00
MTC 109:																			0.00
MTC 112B:													0.5						0.50
MTC 113C:													0.1						0.10

Table 2. Fuzzy classification of the coverage of non-academic competencies in the academic modules.

BEng Degree in Systems Engineering, pathway: Mechatronic Systems	Engineering Mathematics 1	Engineering Science (MTCS3002)	Electrical Engineering Principles	Engineering Materials and Hardware	Engineering Systems Design 1	Introduction to Electrical Engineering	Basic Hand Skills	Basic Automotive Skills	Basic Electrical Skills	Engineering Mathematics 2	Engineering Systems Design 2	Electronic Fundamentals	Analogue and Digital Electronics	Data Communications	Mechanical Systems	General Systems Skills	Basic Mechatronic Skills 1	Basic Mechatronic Skills 2	Safety Engineering & Risk Management	Instrumentation and Control	Power Electronics	Fluid Systems	Control Systems and Design	Engine and Transmission Systems	Advanced Mechatronic Skills	Manitenance of Mechatronic Devices 1	Maintenance of Mechatronic Devices 2	Engineering Management	Power Systems and Design	Digital Signal Processing	Embedded Computer Systems	Individual Project
Engineering disciplines																																
Mechanical Engineering		0.2		0.4			0.3	0.6							1.0	0.7	0.5					0.5		0.8	0.5	0.7						0.7
Electrical/electronic Engineering			0.6			0.6			0.6			0.8	0.8	0.5			0.5				0.9									0.2		0.7
Software Engineering	0.1									0.1	0.3			0.4				0.5									0.6			0.6	0.8	0.7
Control Engineering										0.1	0.2		0.2				0.5	0.5		1.0			1.0			0.5				0.3	0.3	0.7
Engineering cross-disciplinary aspects																																
Mechnical CAD (Mechanical - Software)											0.4				0.1													0.2	0.4			0.9
Electro-mechanical systems					0.1	0.4		0.2			0.1				0.1		0.5		0.2			0.3		0.4					0.7			0.6
Control electronics												0.2	0.4				0.2	0.2		0.6	0.4		0.8			0.8				0.1	0.7	0.5
Embedded control systems (Control -										0.1	0.4	0.3	0.2	0.3				0.5		0.3			0.6		0.7	0.7	0.7			0.7	1.0	0.7
Control of machines and processes						0.1		0.1			0.5				0.2		0.7	0.4	0.2	0.2			0.2	0.3	0.5		0.6		0.3		0.2	0.5
Modelling and simulation (Electronic -										0.2	0.2			0.4		0.1				0.6			0.2		0.4		0.3			0.3	0.7	0.8
Engineering application areas																																
Consumer products					0.1								0.2	0.1					0.1		0.2	0.2				0.7		0.2		0.4	0.6	
Manufacturing and robotics											0.3			0.1	0.1	0.4			0.3		0.3	0.5		0.2	0.5		0.5	0.4	0.4		0.8	
Medical devices																			0.1		0.7	0.2				0.5		0.2		0.9	0.8	
Process control																	0.5	0.7	0.4		0.4	0.6		0.2	0.7		0.7	0.4		0.4	0.6	
Copying, printing, positioning															0.1				0.1		0.5					0.5		0.1		0.9	0.6	
Instrumentation and actuation								0.1				0.3					0.8	0.3	0.5	0.5	0.2		0.3		0.9		0.7	0.2		0.9	0.9	
Vehicles (land, sea, water)					0.1			0.4				0.2			0.1				0.5		0.6			1.0				0.2	0.1		0.6	
Energy generation and storage					0.3							0.1					0.4	0.1	0.5		0.5			0.8			0.7	0.5	0.8		0.3	

Table 3. Fuzzy classification for: Engineering disciplines, Engineering cross-disciplines, and Engineering application areas for the Mechatronics course.

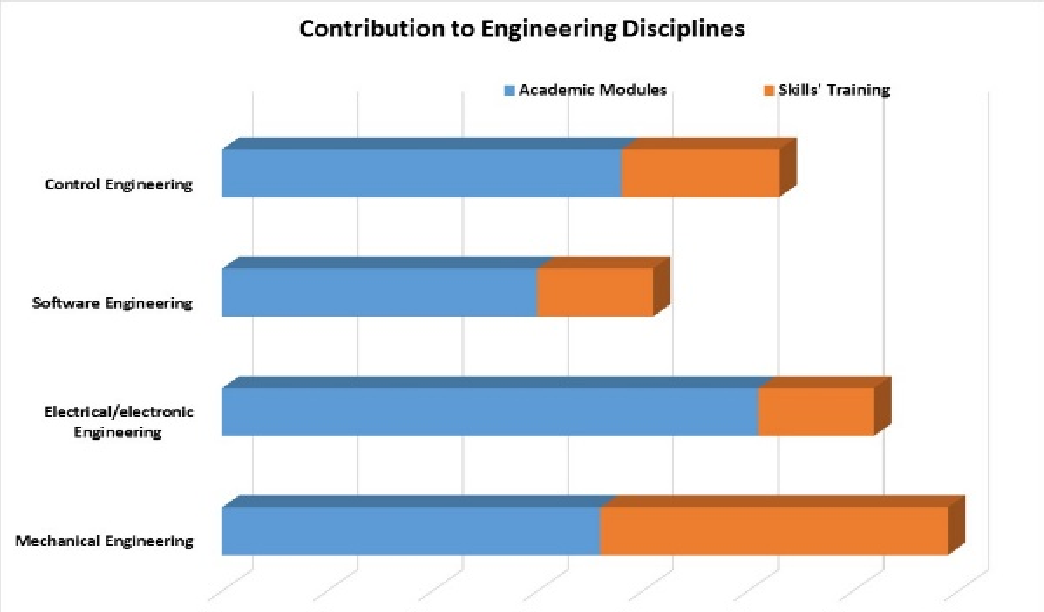

Fig. 1. The strength of the Mechatronics course in the four main engineering disciplines.

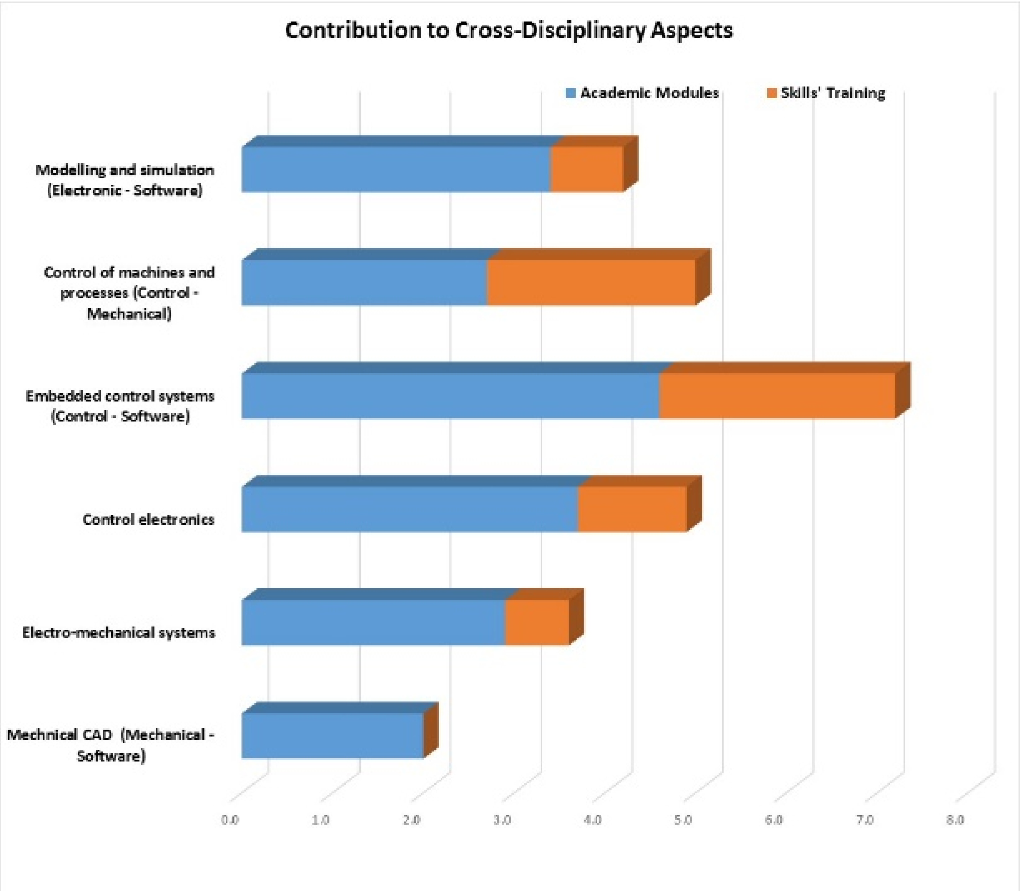

Fig. 2. The strength of the Mechatronic course in the cross-disciplinary aspects

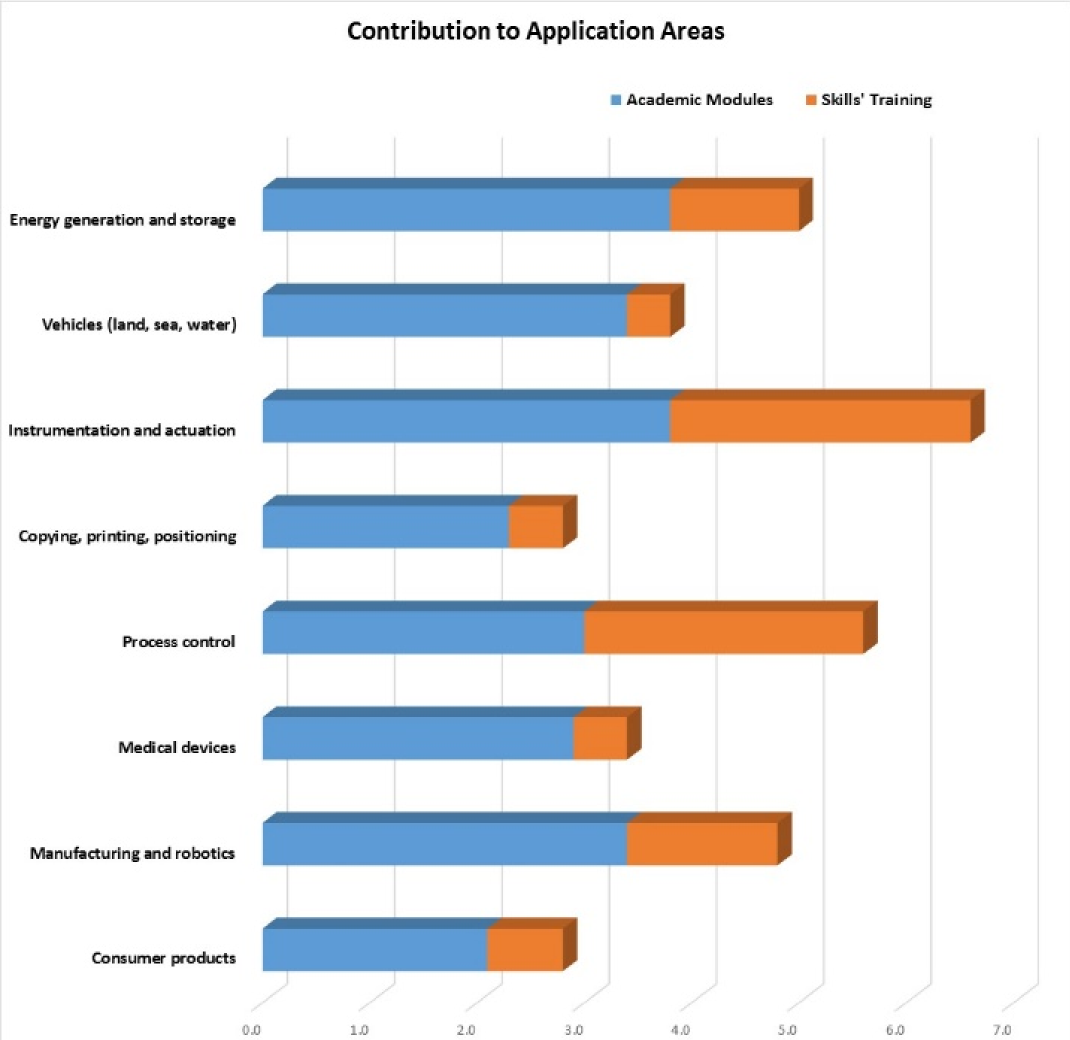

Fig. 3. Contribution of the Mechatronics course to the selected engineering application areas.