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Environment and Effectiveness of Integrated Approach to Project Based and Problem Based Learning in Engineering Education

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Abstract:-This article describes an innovative learning environment designed to support project based learning in engineering education – make-space laboratory. The laboratory has been set-up in two institutions proving successful in enhancing students' engagement with engineering subjects and facilitating their assimilation of required knowledge. The article discusses pedagogical motivation behind the laboratory, presents the flow of work with examples of students' activities and discusses the results.

Keywords:-*Curriculum development, Engineering design, Project based learning*

I. INTRODUCTION

In a study published in 2002 [1] the Authors claim that the "half-life" of engineering knowledge – the time by which half of what engineers know becomes obsolete, is approximately two to eight years. With the rapid progress of technology since then, it is reasonable to assume that this "half-life" has substantially shortened since (it is speculated for example, that the convergence of 3D printing, nanomaterials and software will change the world). This poses a significant problem to engineering education, because the emphasis must shift from: teaching detailed technological know-how, to: teaching the fundamentals and the means/methods how to update oneself, how to continuously acquire the detailed technological know-how, which is changing all the time. The following skills [2] are defined as essential in enabling engineering graduates to successfully operate in engineering environments nowadays:

- independent, interdependent and lifetime learning skills;
- problem solving, critical thinking, and creative thinking skills;
- interpersonal and teamwork skills;
- communication skills;
- self-assessment skills;
- integrative and global thinking skills, and
- change management skills.

Along with many other engineering educators, we believe that the above skills can be efficiently and adequately addressed by implementing project-based learning and problem-based learning education.
In this paper an environment is presented which facilitates the above approach in one integrated laboratory settings. It enables students to perform the project (most suitably a group project, but individual project is also a possibility) through all its stages, from analyzing the problem and conceiving a solution, through design, prototype making, testing, final design, manufacture, and operation. Students are exposed to working environment which, we believe is a reconstruction of an engineering work environment, as good as it is possible in academic settings. This paper is organized as follows:The rest of the introductory section discusses the concepts of project-based learning and problem based learning, along with examples of implementation of those, as reported in the literature. A discussion of CDIO (Conceive, Design, Implement and Operate) approach then follows with comments on how CDIO philosophy fits within the programmes of study presented here.
In the following sections, the adopted concept of integrated approach to project based/ problem based learning is presented. It is discussed how this concept supports students' achieving learning outcomes.Next, the laboratory environment is described in detail. Thus far, it has been built and operated in two universities. The experience of the utilization of this laboratory is presented.Finally, conclusions and areas for future work are presented in the last section.

1.1 Background – What is Project Based Learning

The project based learning is based on the principle that students work on real-life problems individually or in small groups to produce solid results [3-11]. It allows students to engage in investigations [12,13] and promotes students using cognitive tools [14,15].

The researchers [16-20] have reported that project based learning should be implemented at all levels of learning with some minor modifications.The concept of "Project Based Learning" in the engineering curriculum of higher engineering education has been gaining more and more attention over the last twenty years. Examples from Universities in UK and in Australia are provided in Graham's white Paper [21].It can be argued that any modern engineering curriculum has to contain components of project based learning. As a minimum, there must be enough activities to meet the requirements for professional accreditation, which stipulate that students are able to: develop a viable product or system to satisfy product specification, consider business needs, customer needs, product aesthetics and environmental impact. Further, they should be able to effectively explain their work to non-experts. This can be covered in several specialized modules, relating specifically to project management and engineering design, or as part of modules, involving group mini-projects, assessed by demonstration and/or presentation.However, some universities go further, making PBL a learning philosophy, a substantial part of the curriculum, and using project based learning as mechanism for students to learn their engineering discipline of study. Curriculum of the study can be designed in such a way that students get engaged in practical problems, related to their discipline, from the very beginning of their study. Some universities are designing/experimenting with modules of study where there are groups of students working on a project – a group contains students from different years of study – each year participates in the group as a part of a different module, with different learning outcomes. As example, Coventry University adopted the approach called Activity Lead Learning (ALL)[22], where all engineering students (undergraduate and postgraduate) work solely on projects, in interdisciplinary teams, for the first six weeks of their study. Exposing students to practical problems from the very beginning, makes them feel being engineers – this is what they selected as their career in the first place. A similar concept is that of "upside-down curriculum" and teaching theoretical subjects in context of their engineering applications. It also helps to acclimatize in the new environment of higher education, hence helping with retention.
Examples used in Project based learning

1. Design and construction of a switching-mode power supply (SMPS) by Diego [9]. The end product of this project is the application of the knowledge obtained in the theory classes. This experimental prototype design project was assigned in a power electronic subject at the University of Oviedo, Spain. The students were able to design the SMPS in 15 laboratory hours.
2. Static study of a dc-dc converter topologyby Diego [9]. The end product of this project is the application of the knowledge of MATLAB obtained in the theory classes. This project was part two of the SMPS projects and the students presented a MATLAB spreadsheet with the solved static study of the proposed topology at the end of the power electronic course. The students were able to explain their solution to the lecturers and answered their questions. The ability of students to propose solutions to problems enhance their critical reasoning to choose the appropriate solution.

It is sometimes argued that PBL can successfully replace traditional delivery with exams in year one of study. Hence, in some universities, engineering degrees have no exams at all in year one. Instead, there is continuous assessment and substantial projects.
Project based learning can be summarized as follows:

- The students are divided into groups
- Each group is assigned a project. It is hugely beneficial if those projects are related to real world, for instance suggested by University's industrial partners – members of the Industrial Advisory Board
- Each group is assigned an academic mentor/supervisor, whose role must be to only advise/moderate, not to direct.
- The students work on the project through stages: analysis of requirements, design, simulation, building prototype (prototypes) either real or simulated, testing the prototype, final design and build/manufacture.
- The students assume different roles in the team, as leaders for some tasks, facilitators for meetings, presenters to external audience, writing reports, managing against the time-schedule. The group can be (and, if possible, should be) interdisciplinary, because most modern engineering projects are of this nature. The roles assumed by students during the project should rotate, so that all get experience in different roles/functions.

1.2 What is problem based learning

Traditional teaching have been modified by blending it with question-answer, interactive learning and various other methods by which students actively participate in teaching-learning [23-25]. The problem based learning is referred as the learning that results from the process of working towards the understanding or resolution of a problem. The problem serves as a stimulus for the application of problem-solving or reasoning

skills, as well as search for or study of information or knowledge needed to understand the mechanisms responsible for the problem and how it might be resolved [26,27]. The research indicate that students on problem-based curricula report more self-directed learning and better perception of their learning environment than students following more conventional curricula [28]. Frenay [16] reports that the problem based curriculum is mostly intended to enhance deep and meaningful learning, to promote high level capabilities, to develop student motivation and autonomy, and to promote teamwork.
Examples used in Problem based learning

1. Design a system for a 55 kg person to lift a 110 kg weight from the floor and place it on a shelf 2.0 m high in a closet 2.7 m wide by 2.7 m deep [28].
2. A rectangular tank measures 4m long, 2 m wide and 4.8m high. Initially, the tank is half full of water. a) Find the depth of water in the tank after 4000 liters of water have been added to it. b) If the outflow of the water from the tank (after adding 4000 liters) is 5 liters per sec, what is the volume of water left after 55 min? [28]
3. The Shipwrecked boaters run out of drinking water and wonder about drinking sea water [29].
4. What are the environmental and medical consequences of disposal of untreated sewage from Antarctic research station? [29]

These problems contribute to the acquisition of non-technical skills and competences. They allow students to explore disciplinary topics in more controlled manner andto learn how to reach the goal. They alsopromote transferable group skills. In a 12 week trimester 6 hours in each week should consist of supervised problem group work. In problem based engineering curricula, these problems emphasize on problem solving and not problem explanation or understanding and include project work.

1.3 The role of project based learning and problem based learning in engineering education – CDIO approach

The Project Based Learning (PjBL) and Problem Based Learning (PBL) have been, to some extent, formalized in the CDIO approach to curriculum design [30]. CDIO stands for: Conceive, Design, Implement, and Operate. Consequently, CDIO accreditation requires the programme of study to demonstrate how those four components are addressed in modules of study. Starting with a sound knowledge of their discipline, the students proceed to develop personal and professional skills in analytical reasoning and problem solving and in experimental investigation, with emphasis on creative thinking, critical thinking and system thinking. Ethics, professional behaviour and interpersonal skills: teamwork and communication play important role, as all engineering projects in present times require team work and are interdisciplinary. Also awareness of societal and environmental context is a must for engineering projects, so that they can properly address the needs of the users.It has been established that project approaches in project based learning at the industrial management and engineering degree programme changes the learning process of the students [25]. Implementation of this approach in the West has encountered challengesin engineering education. There are more than a thousand engineering courses that involve problem based learning. The main challenge of PBL is doing justice to basic, advanced and specific professional contents, according to curriculum guidelines for engineering courses.

II. THE CONCEPT OF INTEGRATED APPROACH TO PROJECT BASED/ PROBLEM BASED LEARNING

The laboratory environment described below (Make-Space Laboratory) is aimed at providing the students with an experience of all phases of a design project performed in one physical space. Typically, it would be used over a period of several weeks, with a number of hours assigned every week. The students' progress with the tasks week by week. If it is needed, they can also come back to earlier design stages to modify/improve their designs. The activities start with an assignment of a project to a group of students. It could be either a firm allocation, or the students may be able to select from a list of topics. The students can be given the project some time in advance or after entering the lab for the first time. The task/project is ill defined on purpose. This means that some requirements may be conflicting and that the space of possible solutions can be relatively broad. Hence, the students are not expected to follow one, prescribed path but, instead, to show initiative and creativity.The first activity is a discussion and analysis of the project requirements. The students work in teams, with every team appointing a proposer and an opposer. The students may need to refer to their lecture notes or other materials, e.g. by accessing internet. This stage results in several solutions being proposed and discussed and one solution selected for implementation. In some cases also two alternative solutions can be considered for further exploitation.After the solution(s) is (are) selected the students perform design and simulation using engineering software. For that purpose, a number of powerful desktop computers are available, with software packages such as: mechanical design, electrical/electronic design, and fluid dynamics.
If the results of simulations are successful the students move to the next phase. If not, they go back to the discussion table, they perform further analysis – reasons for failure, then modify/change their design and move

to the simulation phase again.The next stage is making a prototype. A 3-D printer is available in the lab which can be used for this purpose. Other possibility could be a breadboard for prototyping electronic circuits.
When the prototype is ready it is tested using test equipment available in the lab. However, before the testing, it may be necessary to do the "fine polishing" of the prototype, because of limited accuracy of prototype making equipment.If the tests are successful, the students move to the next stage. If not, they go back to the discussion table, to find the reasons for failure and decide which stage of the process needs to be modified.
The students have an opportunity to have a glimpse on the manufacturing process and to make a final product (e.g. using CNC machine available in the lab).At this stage, the assigned task is completed, the students exit the lab.The projects undertaken in the modules serviced by the Make-Space Laboratorysatisfy the definition of Project Based Learning (PBL) reported by Milentijevic et al., in 2008 [31] in which they state that "PBL is a constructivist pedagogy that intends to bring about deep learning by allowing learners to use an inquiry based approach to engage with issues and questions that are rich, real and relevant to the topic being studied'. In addition, projects in this module are designed in such a way that they require the students to search and investigate in order to understand, which agree with the Barron definition of PBL[18].

III. HOW THE PROPOSED APPROACH SUPPORTS STUDENTS' ACHIEVING LEARNING OUTCOMES, AS DEFINED BY ENGINEERING COUNCIL UK

3.1 The engineering courses described in this article are designed to comply with accreditation requirements of the Engineering Council UK (ECUK). Those requirements define the set of learning outcomes related to: *Science and mathematics, Engineering analysis, Design, Economic, legal, social, ethical and environmental context, Engineering practice, and General (transferrable) skills*. From amongst those, the Design and Engineering practice are in particular targeted in Make-Space Laboratory. More precisely, citing from the ECUK documentation, the following learning outcomes are of interest:
Investigate and define the problem, identifying any constraints including environmental and sustainability limitations; ethical, health, safety, security and risk issues; intellectual property; codes of practice and standards.

- Work with information that may be incomplete or uncertain and quantify the effect of this on the design.
- Apply advanced problem-solving skills, technical knowledge and understanding, to establish rigorous and creative solutions that are fit for purpose for all aspects of the problem including production, operation, maintenance and disposal.
- Plan and manage the design process, including cost drivers, and evaluate outcomes.
- Communicate their work to technical and non-technical audiences.
- Ability to work with technical uncertainty.

Understanding of, and the ability to work in, different roles within an engineering team.The team work in integrated approach is an interdisciplinary activity that requires a collective effort of specialists with different kind of expertise and cultural background. Through this the team know the strengths and weaknesses of team members. From weekly group project meetings students learn good meeting techniques, disciplined behaviour, minutes taking, and making a good agenda which are essentials of project management. The negotiation skills are developed and polished throughout the course of project. At the same time students take short, intensive, and project supportive courses. Under ECTS all these courses are compulsory and carry 5 ECTS credit points [25]. The first four weeks of the semester 70% of time is spent on team-based group project work and the remaining 30% on study programmes. During subsequent weeks 90% of time is spent on team-based group project work and the remaining 10% on study programmes. At any given time, each member knows what the other members are doing and why. Through the execution of the planned timetable of the group project the learning outcomes are achieved.

IV. DESCRIPTION OF MAKE-SPACE LABORATORY ENVIRONMENT AND EXAMPLES OF PROJECTS PERFORMED BY STUDENTS

4.1 The Make-Space Laboratory, designed and developed at MTC and previously at NU, is an undergraduate version of the University College London (UCL) Institute of Making (IoM) and make space environment. IoM is a multidisciplinary research club for those interested in the made world: from makers of molecules to makers of buildings, synthetic skin to spacecraft, soup to diamonds, socks to cities. The mission of UCL IoM is to provide all makers with a creative home in which to innovate, contemplate and understand all aspects of materials and an inspiring place to explore their relationship to making [32].UCL Make-space is a state of the art workshop where members and guests can make, break, design and combine both advanced and traditional tools, techniques and materials. The facility brings together equipment, expertise and perspectives of making from a wide range of disciplines, encouraging users to engage in the craft, design, technology, history, philosophy, art and engineering of making.

4.2 The adaptation of MTC Make-Space Laboratory to undergraduate level education and integrating with the delivery of vast number of modules allows students and staff in four departments covering twenty different pathways, to move the encountering of engineering application including familiarity with problem solving skills to an earlier stage of development.The Make-Space Laboratory is conceptualizedas a space that permit students to enter with a design problem from one door and through team discussions and utilizing the resources of the lab to exit the lab with a fully tested and superior design or product.The projects can be varied "contextualized" for each group depending on their affiliation (Systems, Aeronautical, Marine or Civil). The objective of a group project from the System Engineering was to design an *impeller* for centrifugal pump that would be superior to the existing impeller provided by the manufacturer. The impeller design was to be created in *CATIAv5* software, manufactured using *rapid prototyping* facility, and subsequently tested in the *laboratory pump* at specified operational conditions.The design/manufacture/testing flow process is given in Figure 1 below. The time estimate is the time required for an expert (concerned member of staff or the lab technician) to complete each process. This is used as a bench mark for students' marking.

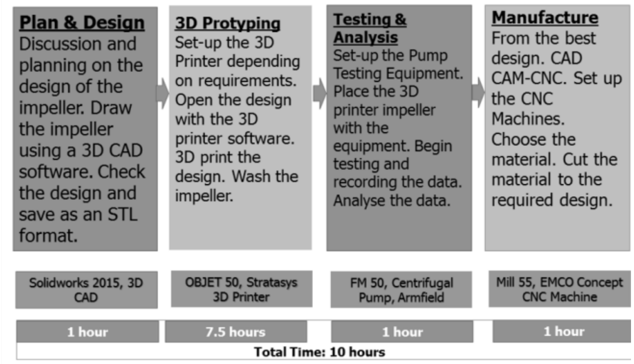

Fig.1 The design/manufacture/testing flow process

Pump is a mechanical device that moves fluid from lower level to higher level due to pressure gradient that it creates. In *centrifugal pumps* the mechanical energy is transferred to the liquid through an *impeller* rotating on a shaft. The main parameters that define performance of an impeller and shown in figure 1 are:

- Impeller speed (angular velocity)
- Blade area
- Number of blades

Fig.2Depicting a typical centrifugal pump

4.3 Computer Aided Design

CATIA is the world leading software for product design. This software is being used by Boeing as a company standard [33]. Formula F1 teams and engine manufacturers employ CATIA [34]. 80% of cars at the 2009 Detroit car show were designed using CATIA [35]. Therefore it was felt that it would be appropriate software to be introduced as early as possible in the program of study. A group of three students first undertook individual design which is shown in the first threeimages of Figure 3. This was followed with a period of discussion and comparison of data. The group final design is given below in figure 3as team design. It incorporates the best features from the initial designs.

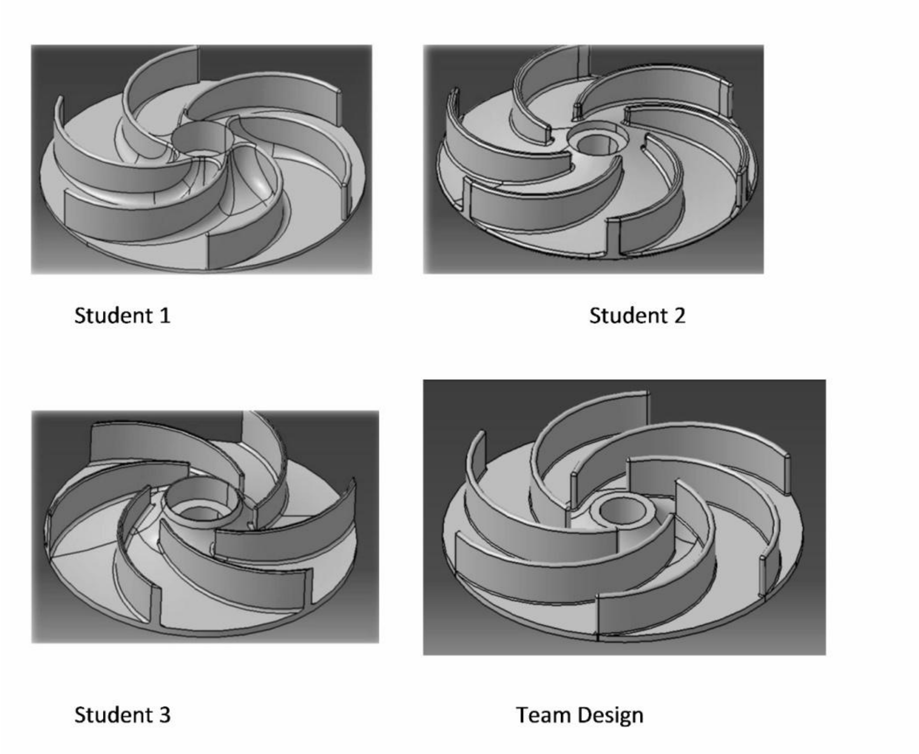

Fig.3Examples of students' designs

Design using solid work is shown below in figure 4. Group of students opted to design the rotor with 6, 7, and 8 blades in an attempt to balance the flow guidance versus the frictional losses.

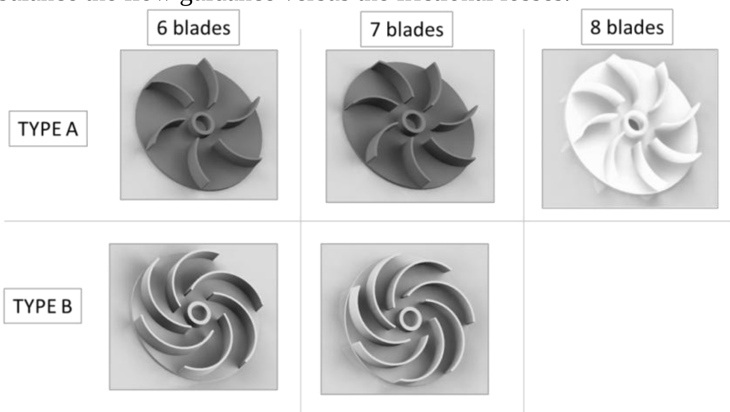

Fig. 4Various rotor design using SolidWorks

4.4 - 3D Printing

Once the design in CATIA is complete, it is then sent automatically to *3D printer* shown below in Figure 5.

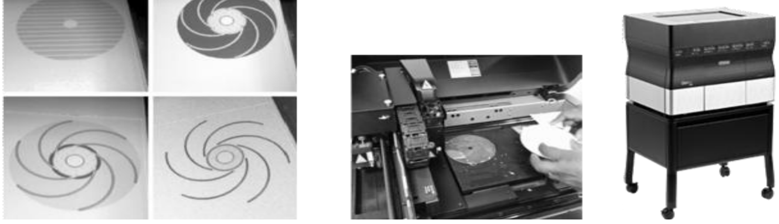

Fig.53D printer, left to right: schematic diagrams for 3D printing – CATIA output, details of the print area, 3D printer used

4.5 Testing

The prototype is then dimensionally measured and mounted on the test rig and the full performance analysis is conducted, evaluating the performance at varying speeds and volume flow rate. Figure6highlights the prototype mounting and testing of two groups carrying the same design task but at two different institutions. Figure 7 shows the physical environment of the laboratory in the two institutions.

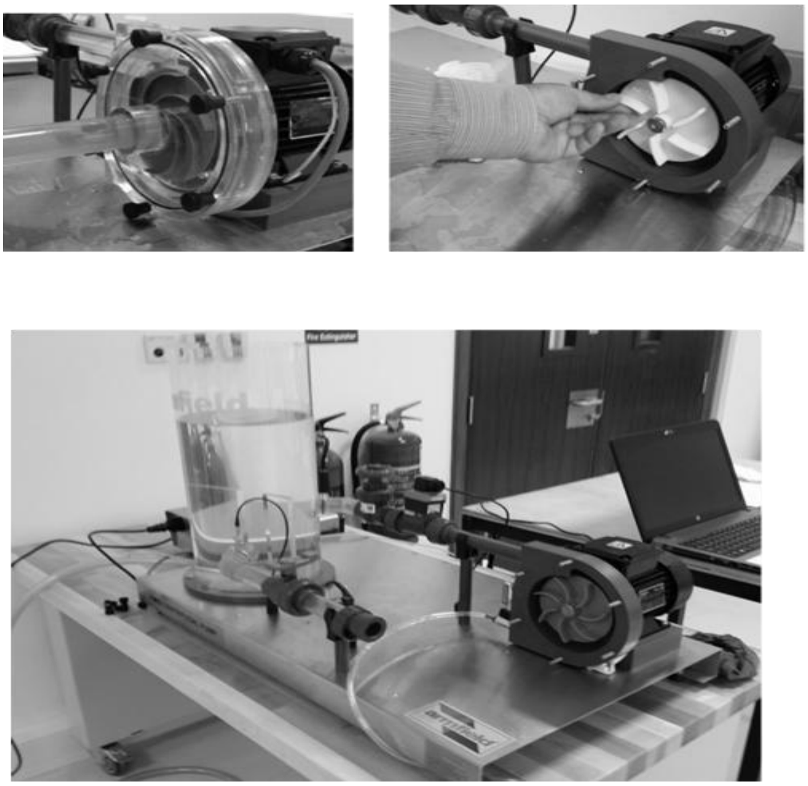

Fig.6Sample results of 3D printing and test-rig

Fig.7Make-Space Lab, top to bottom: Make Space Lab at MTC, Make Space Lab at NU

The best performing students' groups were able to devise innovations to the detailed geometry design of the rotor and the blade profile resulting in improved performance and efficiency of the pumping process. They were able to link the flow speed and pressure distribution with flow detachment and reversals. This was accomplished by using effectively the period allocated for self-directed study and effective coordination between the team members. The figure 8 shows the pump performance at variable settings.

Pump settings	Volume flow rate	Output pressure
1200 RPM	1.4 l/s	35.5 kPa
1500 RPM	1.76 l/s	56.2 kPa

Pump settings	Pump efficiency
1200 RPM	87.5%
1500 RPM	81%

Fig.8Pump performance obtained during the lab session.

4.6 Results

The Figure 9 (below) shows the results distribution for all modules delivered at level 3 for the academic year 2014/2015 from A to F. These modules are covering the subjects of engineering science, electrical engineering (two modules), mathematics, engineering materials,and engineering system design (ESD1). ESD1 is the only module offered during the first year of the degree program that uses fully the capabilities of the Make Space Lab. The combination of practical and theoretical integration on a project based learning exercises seems to have ensured engagement, interest and desire to learn and self-study resulting in the highest percentages of As and lowest percentages of Fs.

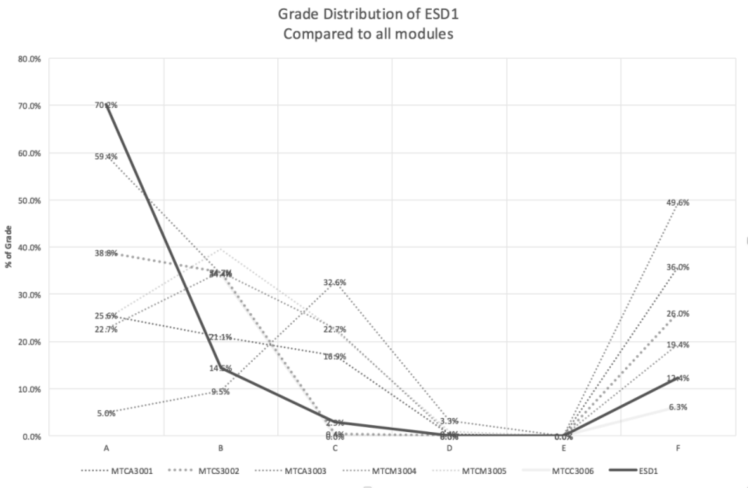

Fig. 9 Comparison of grade distribution for six Level-3 modules.

V. CONCLUSIONS AND FUTURE DEVELOPMENTS

This paper has presented an environment specifically prepared to teach students the principles of engineering system design using project-based learning approach. The laboratory has been build and used for courses at undergraduate level, so far in two academic institutions in two different countries. In both cases, the results are very encouraging, demonstrating increased students' engagement with the subject and better results than for other modules running in parallel. The present set-up of the laboratory enables designs and testing related to fluid mechanics. The future plans are to expand the range of possible projects. The first choice (already under commissioning is for aerodynamics designs (aircraft, automotive). This requires, in addition to the equipment already available, a wind tunnel facility. Further plans are to expand towards electronics, embedded systems and automation. This area is promising, because of wide availability of rapid prototyping electronic boards, and rapid prototyping software tools. Also, testing of designs can be performed relatively straightforwardly with oscilloscopes and computers. The projects could combine elements of programming, electronic board design and wireless communication.

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