MAPPING DESIGN THEORY INTO INDUSTRIAL APPLICATIONS : BEST PRACTICES FROM MALTA

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ABSTRACT:

Industry is keen on employing well trained design professionals. The ability of being able 'to map' theoretical design knowledge into practical design applications is one of the best ways by which graduates can be measured when being shortlisted for design related jobs. Achieving this type of 'academic formation' however requires an educational programme specifically structured towards cultivating this 'mapping ability'. This paper describes the engineering educational programme that has evolved over a period of more than 10 years at the University of Malta (UOM), precisely designed towards achieving this 'mapping ability'. Like many small island states, Malta's economy is very sensitive to its ability to have knowledge based workers. Over the years, successive governments were being advised to shift towards designing *and* manufacturing. This motivated the authors to phase-in the 'DT2P' (*Design Theory to Practice*) model of design education, based on the integration of the *basic design cycle* and the *Integrated Product Development* model.

Keywords: pedagogic approach, engineering design, product development

1. INTRODUCTION

The island of Malta, has since the 1960s been driving an industrialization programme with the aim of attracting *Foreign Direct Investment* (FDI). A number of incentives such as attractive tax rates and good industrial park rates did indeed result in a number of firms setting up shop in Malta.

However, the entities attracted came to Malta primarily for low labour cost activities such as fabrication and assembly. These types of low added value entities did in fact generate jobs and career opportunities such as in management at that time. However, this also meant that production of products in Malta heavily depended on products designed abroad. Over the years, a number of such manufacturing firms lost their competitive edge due to lower labour cost markets emerging in North African and Asian regions. This became even more critical when Malta became a full member of the European Union (EU). This trend meant also that higher education needed to shift from focusing on mass production techniques and management to one addressing both the design and manufacture of artefacts, i.e. education on product development technologies and management.

Like many small island states, Malta's economy is very sensitive to its ability to have knowledge-based workers. Over the years, successive government were being advised through various studies (Malta Federation of Industries & Malta Chamber of Commerce, 1996) to shift towards not only manufacturing products in Malta, but rather towards designing *and* manufacturing. At the same time, industrial associations were skeptical on how a small island state such as Malta can be actively involved in the knowledge based activity of design.

The authors, in their role of academics at the Faculty of Engineering at the University of Malta (UOM) felt that this situation had to be addressed. Using their 'design problem solving' background they embarked towards seeking ways to how this challenge (see Figure 1) could be addressed.

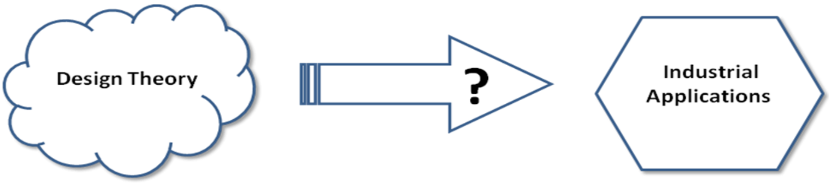

Figure 1: Challenge of Mapping Design Theory to Practice

Their exploration of problems associated with amplifying academic training for the exploitation of design within the Maltese industrial sector resulted in a number of questions that had to be addressed, namely:

- ☐ What mix of topics had to be included in a degree programme to help graduates be prepared for applying their theoretical knowledge to practical problems?
- ☐ In particular, what design and manufacturing knowledge and practice had to be included in this formation?
- ☐ How could students be motivated in choosing modules related to design as their focus of studies?
- ☐ Can such graduates' academic formation be sufficient by just an undergraduate degree, or would it be necessary to also have postgraduate training?
- ☐ Could industrial stakeholders be regularly involved in this graduate formation, without too much resistance from the formal academic decision makers normally involved in higher education?

2. THE 'DT2P MODEL' OF DESIGN EDUCATION

To achieve the objective of mapping design theory into practical applications, the authors converged towards phasing-in an academic programme based on what they termed the DT2P (*Design Theory to Practice*) model. As illustrated in Figure 2, the goal of the DT2P approach is to allow design theory in the form of a range of systematic methods, to result in design solutions/concepts that can be readily taken up by industry.

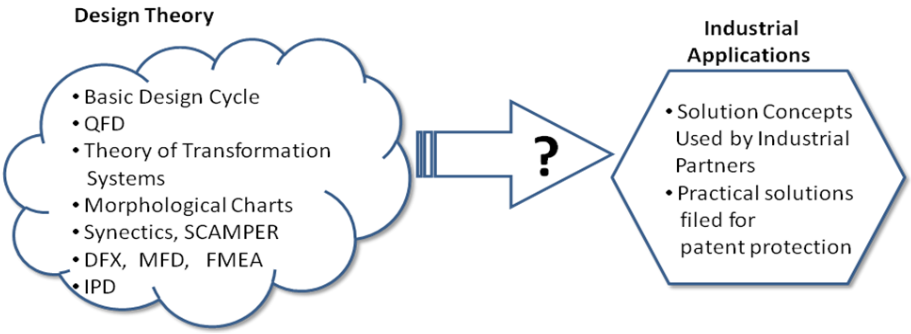

Figure 2: Underlying principle of the DT2P model of design education

To help address some of the questions raised in the previous section, the DT2P model is based on the integration of :

☐ the *basic design cycle* (Roozenburg & Eekels, 1995) with

☐ the *Integrated Product Development* model (Andreasen & Hein 1987)

The reason for basing the academic formation on the IPD model (Andreasen & Hein 1987) is that as outlined in Figure 3, in this product development approach, concurrently took into consideration the development of the product and its production systems, simultaneously with the consideration of market/business needs. Thus, trough the IPD approach, the process of converting a customer need into a real world practical application, is thus based on three pillars: product engineering, production and market/business management aspects. This is because converting a theoretical design solution into a practical solution requires not only a functionally product structure, but also a product solution that can be relatively easy manufactured and at acceptable target cost and delivery dates – hence correctly managing such a process is a necessity. It is for his overall reason, that the DT2P model of design education at the University of Malta employs the IPD model of Andreasen and Hein as a foundation. The IPD model allowed educators at the University of Malta to structure a set of undergraduate and postgraduate degree programmes that try to achieve this goal.

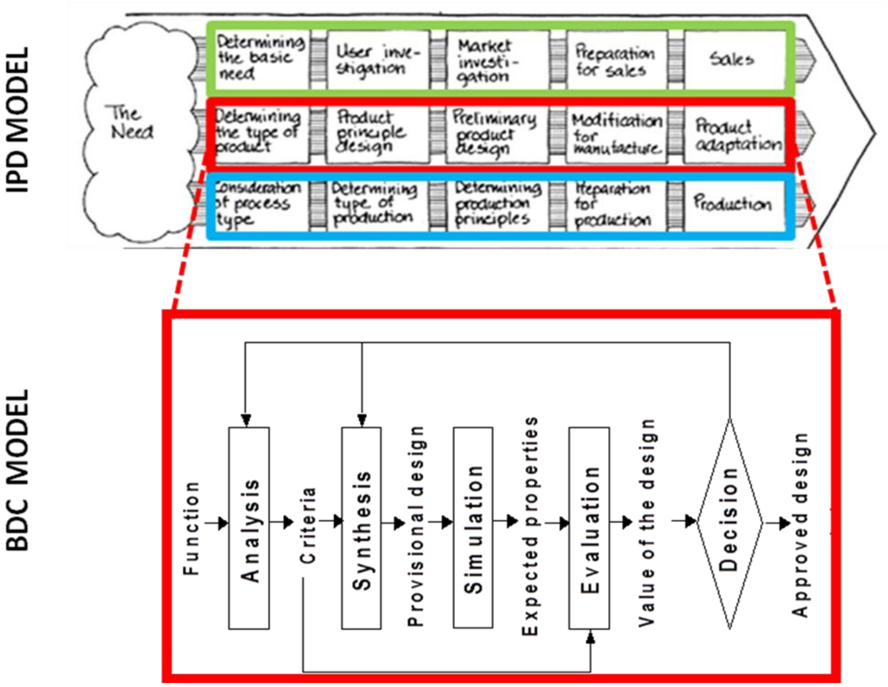

Figure 3: DT2P Model Based on The Basic Design Cycle (Roozenburg & Eekels, 1995) & IPD Model (Andreasen & Hein 1987)

The authors felt that whilst IPD provided a good basis for answering the question on what topics should be included in the academic formation, it was however to high-level with respect to how actual training in design theory could be best achieved. For this latter reason, following exposure to various design process models, the authors chose to complement the IPD model with the *basic design cycle* (BDC) (Roozenburg & Eekels, 1995).

The BDC model provides a descriptive approach of how design in the engineering domain typically takes place. The BDC starts with the analysis of the function an artefact is intended to meet (see Figure 3). The outcome of the problem analysis activity consists of a set of criteria which are translated into a *Product Design Specification* (PDS). During the synthesis activity working principles and principle solutions are generated to address requirements in the PDS. The synthesis activity is the crucial stage of the BDC. The outcome of synthesis is a provisional design solution which is simulated in the subsequent activity. The outcome is a list of expected properties which are evaluated in the evaluation activity with respected to the design criteria. The value of the design is either accepted or rejected, in which case, the designers goes again through the BDC. As explained later, this BDC thus helped identify which systematic design tools and methods should form part of the mechanical engineering student formation.

3. AN 'INDUSTRIALLY ORIENTED' MECHANICAL ENGINEERING DEGREE PROGRAMME

As a result of the underlying pedagogic approach provided by the DT2P model, the Bachelors in Mechanical Engineering at the University of Malta has over the years been restructured to address these goals. DT2P resulted in academic degree structure composed of a number of subject areas aimed at achieving a number of learning outcomes, which are shown schematically in Figure 4.

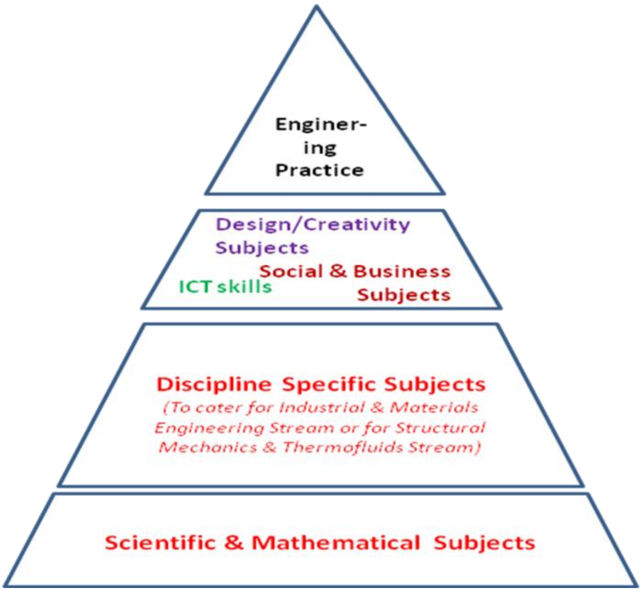

Figure 4: Subject areas included in academic formation

For practical reasons and to align with the *European Qualifications Framework* (EQF)[1], the overall underlying pedagogic approach has been transposed into a 4 year undergraduate bachelors degree of 240 ECTS combined with an optional 90 ECTS Masters degree specializing further in Integrated Product Development (see Figure 5).

A number of design-related, common core formation and stream oriented modules are taught throughout the Bachelors degree course. First year students are taught the language used by mechanical engineers in expressing solution ie. engineering drawing. This module covering basic engineering drawing skills such as orthographic views, dimensioning, standard conventions associated with threads, welding etc. In addition, basic industrial design sketching skills are introduced.

In the second year, the students are exposed to *Computer-Aided Engineering Design* (CAED) support tools. Complementing the theoretical background such as *feature-based modelling*, *CAED customization* and *CAED in collaborative design environments*, students are trained on a commercial CAED application.

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[1] http://ec.europa.eu/education/lifelong-learning-policy/doc44_en.htm

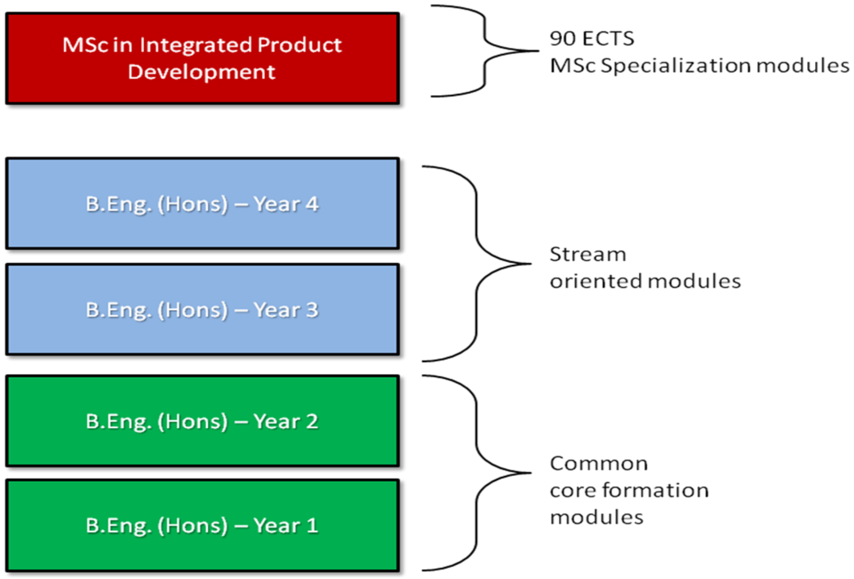


Figure 5: A 240 ECTS bachelors degree & 90 ECTS MSc formation

In the third year, students are taught systematic design methods to solve a design problem in different stages of the basic design cycle. Examples of tools which are taught include *synectics*, *morphological charts* and *DFX* (e.g. *Design for Manufacturing* and *Design for Emotions*). Another design related module which is taught in the third year deals with *mechatronics system design*. It is aimed at providing students with knowledge on the principles of mechatronics in product and process development.

In the fourth year, students undertake the *final year project* (FYP), where they apply the knowledge and skills learnt throughout the course. In projects where students have to design and manufacture a component or an assembly of components, the use of freehand sketching, rather than the use of CAED, during the conceptual design stage, is strongly recommended (Farrugia, Borg, Camileri, 2011).

3.1 DESIGN THEORY, FUN AND PRACTICE

To enable students to learn to practically apply knowledge on design theory acquired throughout the course, the DT2P pedagogic approach includes a mix of *collaborative*, *project* and *individual based learning*.

As part of their second year CAED technolgy module, small groups of Maltese students are engaged in a synchronous collaborative design group exercise with students at the University of Strathclyde, UK (see Figure 6). The exercise introduces students to the particular tools and practices necessary to complete the design of an artefact in a distributed environment. The exercise is designed to be a hands-on experience which highlights the real issues of sharing and communicating design information with technological constraints. Students are assigned a simple design task (e.g. the design of an innovative hospital door handle) and they have to use different synchronous tools such as videoconferencing, and *Skype* to communicate their concepts with their team mates in UK. As an incentive, Maltese students are given a certificate of participation, issued by the University of Strathclyde.

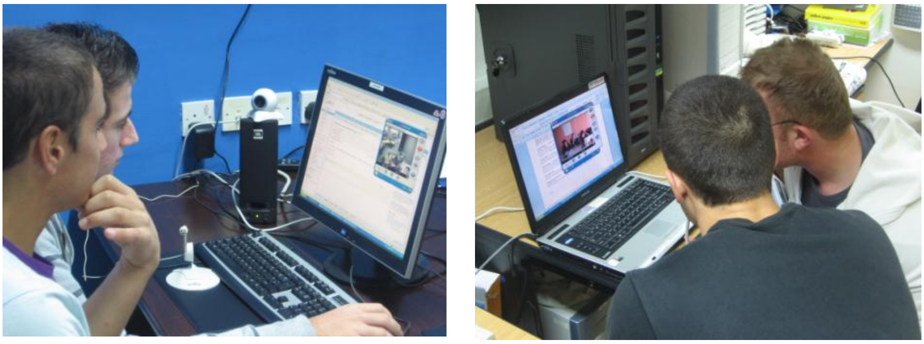


Figure 6: A Global Design Exercise between Maltese & UK students

A core part of the 'DT2P' (*Design Theory to Practice*) model of design education is providing the necessary theoretical foundation and hands-on-practice to the design process utilizing the Basic Design Cycle. As outlined in Figure 7, this is achieved through a 10 ECTS Engineering Design module composed of a 4 ECTS theoretical part carried out in the first semester of the third year of the bachelors degree, coupled with a 6 ECTS hands-on design projects carried out in semester 2 of the same year.

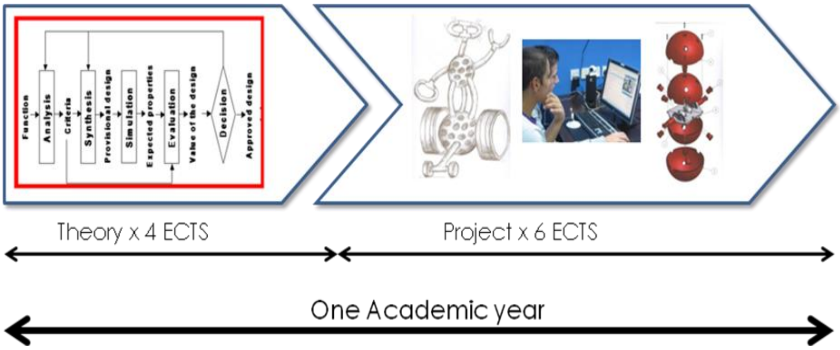
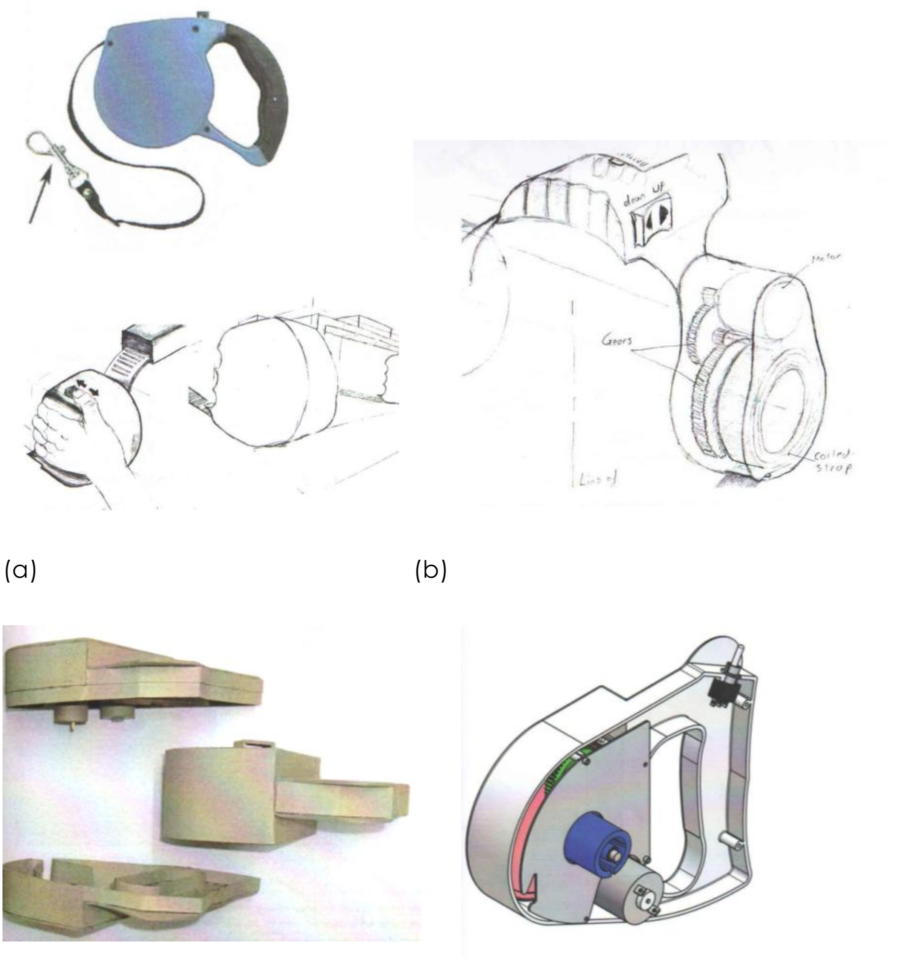


Figure 7: Engineering Design Module Structure

This means that in the 4 ECTS theory covered in semester 5, students are provided with the theoretical training in different design methods used for different activities forming part of the BDC. Such methods include QFD, synectics, function-means, morphological charts, SCAMPER, Design for Manufacture & Assembly (DFMA) and FMEA. Following this training, in semester 6, students are assigned a *group-based*, engineering design project aimed at providing students firstly with the opportunity of employing relevant methods learnt in semester 5, in order to systemically address the design problem at hand. Secondly, such a project provides students the experience of a ‘team-based’ design approach as typical in industry. Each group must provide a technical report disclosing how design tools used in the different activities of the basic design cycle were employed, detailed engineering drawings, physical prototypes, and flyers aimed at marketing the design product. In addition, as a group deliverable, students have to submit a *YouTube* video describing the design process they went through. To keep track of the progress made by each group member, an individual A5 design logbook has to be submitted. The logbook contains a record of all the design activities carried out (e.g. group brain storming sessions, sketches, photos of similar products on the market, use of *SCAMPER*, synectics, calculations, meetings etc.) during the course of the project.



(a) (b)

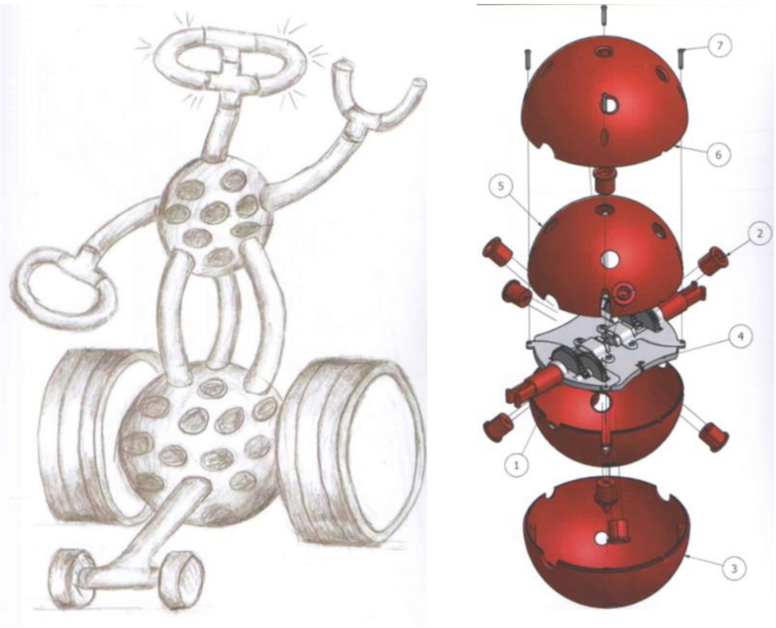
(c) (d)

Figure 8: Use of (a) ‘Adapt’ in *SCAMPER* (b) sketching (c) physical modelling (d) CAED modelling in a typical engineering design project

In one design project, for instance, the students generated the handle of an automatic stock wearing device for the elderly on handles of existing products, such as a dog leash and a hack saw handle. In this case the students used the ‘A’ for ‘Adapt’ in the *SCAMPER* creativity technique

(Figure 8a). Sketching together with simple physical modelling (Figures 8b, 7c) helped a lot the students in generating various form concepts students during design synthesis. It is only after that the students had devoted considerable amount of time in conceptual design that they resort to detailed CAED modelling (Figure 8d). This correlates with the design practice in industry, in which sketching is still widely used (Muller 2001).

Another typical project undertaken by our third year students is depicted in Figure9. It concerned the design of a toy for 6+ years that promotes creativity in children. Again this case, students dedicated a considerable portion of their time on generating solutions via sketching (Figure 9a). Three-dimensional CAED modelling took place late in the design process (Figure 9a). Morphological charts were also used to systematically explore the whole solution space.



(a) (b)

Figure 9: Use of (a) freehand sketching (b) CAED modelling in the ‘creativity-enabler’ toy project

To help motivate students in appreciating industry is interested in innovative design solutions, the Faculty managed to obtain an annual student design project award from Malta Enterprise, which is Government’s agency responsible for industry and for attracting Foreign Direct Investment (FDI) to Malta. Non-academic judges assess the degree of innovation and potential marketability of the product. Over the years, this award has been seen as benefit of adopting the DT2P model of teaching design.

3.2 INDUSTRIALLY-PARTNERED FINAL YEAR PROEJCTS

Undergraduate training reaches its climax when in their fourth year, students carry our a final year project (FYP). For these projects, students can propose their own ideas or else, in case of industrial-partnered projects, they have to solve a practical problem provided by industry. Once again, the mechanism of employing industrially-partnered final year projects has proven to be attractive to a number of industrial partners, this evident from the fact that many return year after year with sponsorships for design projects solving a range of problems they have. Some industrial partners with which the *Department of Industrial and Manufacturing Engineering* (DIME) regularly collaborates include *Toly Malta Ltd*. (producers of cosmetic cases), *Playmobil Malta* (manufacturers of toy products), *Baxter Malta Ltd.* (manufacturers of medical components) and *Methode Electronics Malta Ltd.* (producers of automotive switches). Once again, to help map theory to practice, getting industry or professional associations sponsoring student project awards has been demonstrated to help.

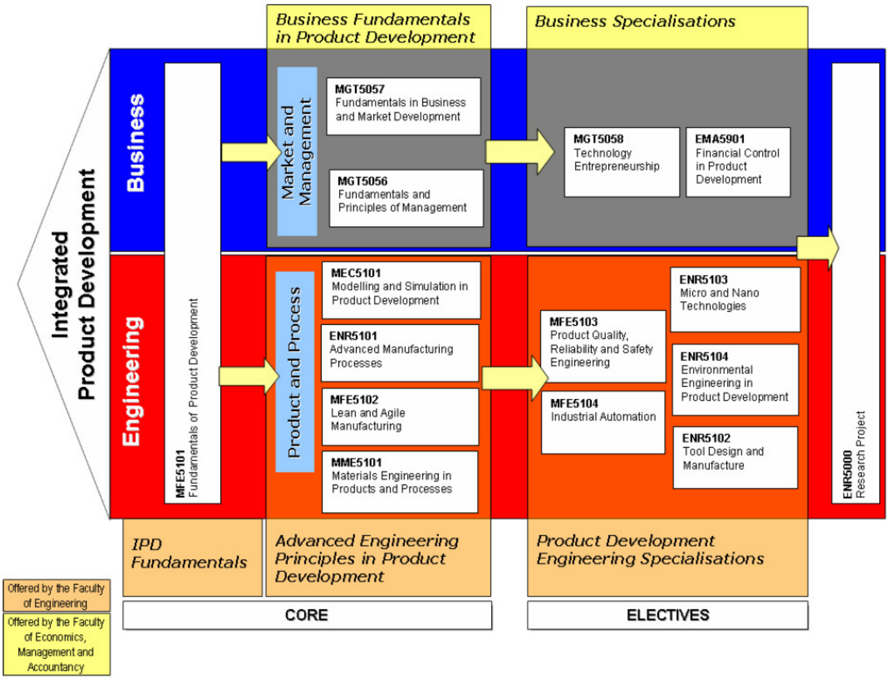


Figure 10 : The 90ECTS, M.Sc. IPD course structure

4. AN MSC COMBINING 'ENGINEERING & MANAGEMENT' LEARNING OUTCOMES

Although the undergraduate bachelors degree in mechanical engineering (industrial engineering stream) is sufficient as a foundation to allow students the ability to map design theory to practical applications, a more holistic pedagogic approach is achieved when students further their studies through an MSc in IPD. As reflected in Figure 10, the M.Sc. IPD course structure is based on the three pillars of the IPD model. Students have a core module in which the fundamentals of product development are taught, where practical industrial examples, such as the development of complex products (e.g. smartphones) are taken as case studies. Besides the purely *product engineering design* aspect, students are taught subjects related to *business fundamentals* (e.g. market development) and *advanced engineering* principles in product development (e.g. rapid prototyping and lean manufacturing). Furthermore, they can specialize in both streams by selecting elective modules such as technology entrepreneurship and tool design and manufacture. In addition, the postgraduate students have visits to established manufacturing (see Figure 11).

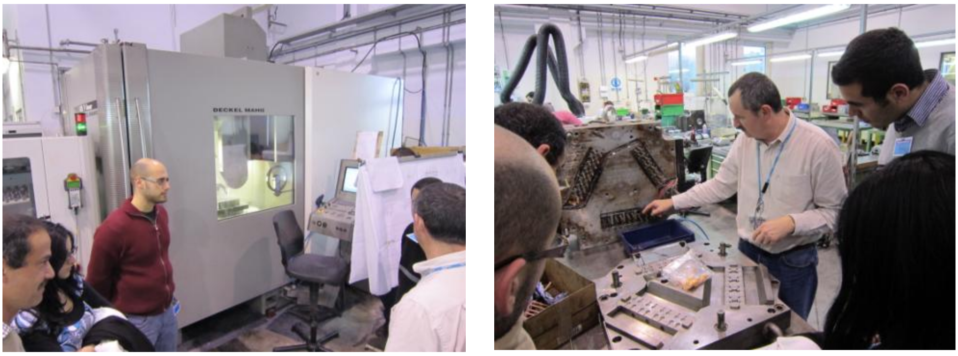


Figure 11: Visit of M.Sc. IPD students to *Playmobil Malta*

5. AUXILIARY DT2P MECHANISMS

Besides the engineering design group projects and final year projects, other auxiliary mechanisms are employed to help map design theory to industrial applications.

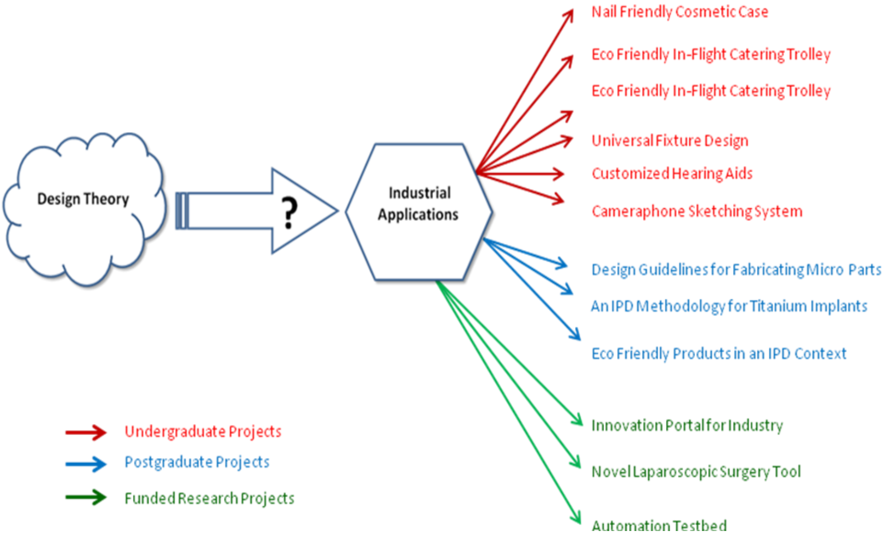


Figure 12: Auxiliary DT2P Mechanisms

As reflected in Figure 12, these include *National Research & Innovation* (R&I) projects, *European Regional Development Funds* (ERDF) projects and *M.Sc. IPD* projects. An example of an MSc. IPD project whereby a postgradaute student mapped design theory for practical industrial applications, dealt with the generation of DFX guidelines for micro compression moulding components at *Trelleborg Sealing Solutions* (Mifsud 2009).

In addition, some graduate engineers are also employed as research assistants to nationally funded research projects. One example is the IDELAP[2] project that dealt with research into the design and manufacture of a multi-functional laparoscopic surgery tool. Design synthesis tools such as synectics and *SCAMPER* were fundamental in generating innovative solutions. As evidence of how theory is mapped into practical applications, it should be noted that this work resulted in the filing of a patent with WIPO.

Similarly, the ERDF project AIM[3] employs research assistants. In this case, the aim is at developing a portal by which relevant stakeholders in industry can practically amplify the degree of innovation in their products and services via collaboration and simulation tools.

Besides nationally based knowledge transfer activities, students following the DT2P pedagogic approach are invited to attend optional, overseas formation activities. This consist of a number of industrial visits which are organized by *DIME* in different European countries. Examples include industrial tours to France to see the Airbus A380 assembly plant in Toulouse and to Germany to visit the manufacturing line of the *BMW 3 series* model, the manufacturing of civil and military helicopters at *Eurocopter* and the production of locomotive braking systems at *Knorr-Bremse* in Munich.

6. CONCLUSIONS & LESSONS LEARNT

After several years of utlizing the DT2P' *Design Theory to Practice'* model of design education, can one conclude it is achieving what it intended to achieve? And if in the positive, were there lessons learnt?

Well, time is indeed required to be able to assess if the DT2P training invested in engineering students years back will reap the benefits intended. However, the fact that more students are embarking on postgraduate training to both masters and doctoral level in engineering design related fields, is somewhat an indication that students do see career prospects in this sector. In addition, the fact that industrial partners repeatedly come back to financially sponsor design related projects to solve problems they have, is also good evidence that the work of UOM Engineering students is being considered practically useful. Also providing a degree of evidence that the DT2P model is contributing to the mapping of design theory to practice applications is the fact that the University has invested in a couple of patents arising from related work. Based on these indicators, the authors feel that the DT2P has indeed contributed to the academic formation of engineers that are able to map design theory to practical applications. As a result, the authors would like to share a few lessons learnt:

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[2] http://www.eng.um.edu.mt/~dmeu/idelap/

[3] http://www.eng.um.edu.mt/dml/AIM/

☐ A degree programme needs to have a mix of engineering and management topics, coupled with social skills;

☐ To generate design solutions that can be realized in practice requires thorough training in Design For 'X' (DFX) methodologies;

☐ Providing sponsored design innovation awards helps motivate students;

☐ There is no short-cut to effective long-term training. An undergraduate degree combined with a relevant MSc degree programme provides more opportunity to allow students to map design theory to practice;

☐ A good way to regularly involve industrial stakeholders is to invite industry to provide students with real problems that need to be solved;

☐ Remember to manage your 'intellectual property' (IP) well;

☐ Maintain good working relationships with industrial stakeholders. Meeting them regularly is not a luxury. More importantly, at the end of sponsored projects, do organize a post-project presentation to Management and listen well to their constructive feedback!

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