INCORPORATING THE FISCHERTECHNIK BRICKS INTO UNDERGRADUATE MECHATRONICS COURSES

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ABSTRACT

Mechatronics courses at the undergraduate level often consist of classroom and laboratory sections. The classroom section introduces the mechanics, devices and control techniques involved in the technology, while in the laboratory section, certain mechanisms like motor-gear sets or robot arms are prepared and students will implement controls by programmable logic controller (PLC) or other graphical-user-interface (GUI) tools over them. The mechanisms are fixed and compact and do not permit decomposition and reassembling, which prevents students from getting a real feeling of the whole system. To improve this, Fischertechnik bricks have been incorporated to aid the course. The Fischertechnik features that, in addition to the fundamental building elements, it includes mechanical elements like gears, wheels, electrical elements like actuators, sensors, which can easily be assembled to form a real industrial mechanism ready for control. Such a laboratory scheme goes through a complete flow including plant assembling, controller designing, and performance verification. Students are supposed to benefit in every phase through the course.

INTRODUCTION

Engineering education in the 21st century is facing a challenge marked by knowledge doubling every few years. The design process of engineering products has been revolutionized by the advent of the information technology, the computing, and the micro-electronics. These revolutions are reflected significantly on engineering education.

Mechatronics is the application of mechanical engineering, control theory, electronics, information technology, and computer science with equal strengths. It is an advanced technology of blending the mechanical structure and interface with transducer systems and the micro-controllers with other appliances. It also means the synergistic use of precision engineering, control theory, real-time software, computer hardware, and sensor and actuator technology to design more functional and adaptable products and processes. Hence, to be able to really understand the interaction between the different elements, building a complete mechatronical system is necessary (khan [1], Yost and Krishnan[2], Jarrah[3]).

The quest of seeking a new way to teach the mechatronics for the undergraduate students has lead educators to explore the potential of using the programming robotics as the educational platforms. For example, Halmsted University uses the autonomous LEGO mobile robots in games of golf, soccer, environmental clean-up and navigation in the one-semester course on mechatronics systems (Website[4]). Brigham Young University offers a mechatronics course that requires students to implement mechatronics principles by designing and building small scale autonomous robots (Hoopes *et al*[5]). University of Detroit Mercy designs a team-oriented, project-based course in mechatronics to integrate the teaching of mechatronic principles throughout the relevant engineering curricula by hands-on activities (Krishnan *et al*[6]).

Except using programming robotics from LEGO, the programming robotics provided by the Fischertechnik in German (Website[7]) has been incorporated into mechatronics course to ignite student's interests of mechatronics and to instill engineering skills, scientific interests, computer acquisition, general ideas and creativity among students. Fischertechnik products have been used by the most sophisticated educational technology projects in the United States. One such national program is Project Lead The Way, now in 26 of the 50 states. This organization seeks to form

Figure 1: Components in the Fischertechnik Experimental Robot

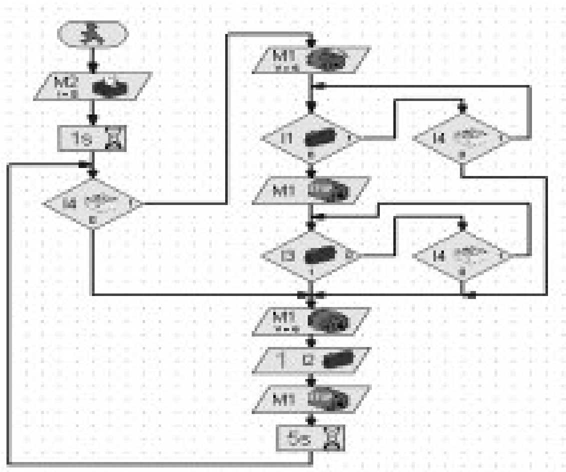


Figure 2: Control example programmed with the ROBO Pro

partnerships between public schools, universities and industry to promote engineering education, and have chosen Fischertechnik as the exclusive model construction system to teach control automation (Website[8]).

In this paper, the implementation of basic modules built by the Fischertechnik bricks on the educational platforms will be described. With these platforms, students are asked to implement controls by PLC or other GUI tools over them. On the other hand, team-oriented projects are also offered in our laboratory for students to explore some specific topics through the plant assembling, controller designing, and performance verification.

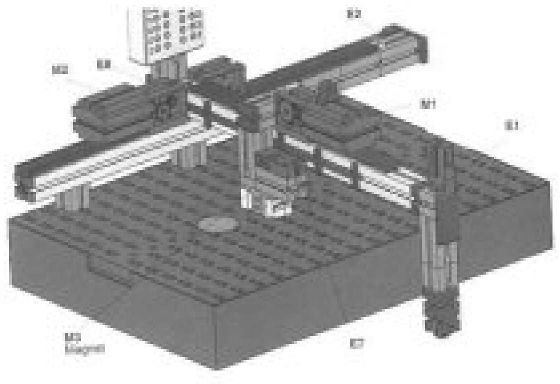
Hence, the purpose of proposed mechatronics course is to give students hands-on experiences with real problems, give students experience in understanding and implementing the basic mechatronics principles by ‘doing’, give students confidence in their ability, develop advanced coordination and teamwork skills for students, and thus obtain technical position within industry.

THE BASIC MODULES OF THE EDUCATIONAL PLATFORM

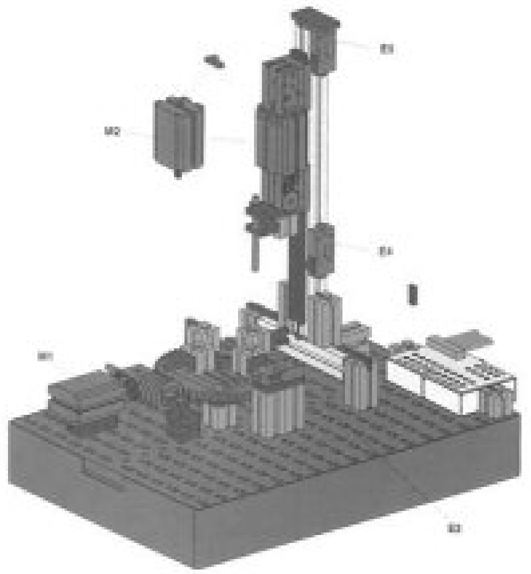
The Fischertechnik Experimental Robot is chosen for the platform of the course. These Fischertechnik bricks allow a multitude of systems and 3D models to be created by slotting precision-engineered parts together and provide a hands-on approach to technology education. Other reasons for choosing Fischertechnik Experimental Robot as the platforms were that it is inexpensive and it is the flexible construction system.

The Fischertechnik Experimental Robot contains 2 light sensors, 8 touch sensors, 2 motors, 4 gears, wheels, beams, bricks and assorted pieces as shown in **figure 1**. The controller of the Experimental Robot is the computer interface which can enable the models built by the students to be connected to the computer for infinite exploration and innovation. The Experimental Robot also comes with visual programming software, ROBO Pro, to facilitate the programming and control of robotics devices through the simple construction of flowcharts with an intuitive Windows-based graphical interface. **Figure 2** shows a control example programmed with the ROBO Pro.

Fifteen basic models have been provided by the Experimental Robot, which can be used to learn the control of key bank, traffic light, motor winch, turtle, freight lift, machine tool, fan, washing machine, sorting system, automatic door, computer eye, radar, robot arm, storage, antenna rotor, teach-in-robot. Some of the basic models are shown in **figure 3**, where **figure 3(a)** shows a storage control system and **figure 3(b)** shows a machine tool.



(a) Storage control system



(b) Machine tool

Figure 3: Some of the basic models provided by the Fischertechnik Experimental Robot

THE MECHATRONICS COURSES

This is a 3-credit, semester-based course that is the hands-on laboratory. The majority of the students taking this course are seniors in Electrical Engineering. The focus of course is on learning the basic principles of mechanisms, sensors, actuators, control and programming. A prominent feature of this course is the strong emphasis on hands-on activities to support learning.

Figure 4: A system designed and built by one of the groups

The course is divided into three sessions. During the first session, students use the GUI programming language, ROBO Pro, to control the basic models through the Fischertechnik control interface, ROBO interface. In the second session, students are asked to use the PLC to control the basic models through interface designed by our laboratory. After finishing these works, students have a good idea about basic principles of mechanisms, sensors, actuators, control and programming. Then, the students have to design and build an autonomous vehicle that was capable of navigating itself along the pre-designed path, and then having a competition at the final week of the course. A formal technical report is required for each assignment.

The projects

In addition to the lectures and laboratory, the team-oriented projects are also offered. Students have to learn all aspects of mechatronic system design to finish their projects. They must learn how to construct the mechanics of a plant as well as properly connecting together the controller, sensors, and the actuators, and by so, they are building intuitions about concepts such as structural stability, gear ratios and control. For the project grade, each team must write a final report, and demonstrate the work they designed and have a formal presentation to the classes and the teachers.

Figure 4 shows a student project development. This is a system simulating processes of material transportation, manufacturing and monitoring in an automatized factory. The entire development includes mechanism assembly, control Implementation and process monitoring. The frame of the automatic process can be divided into four major parts, a 3-degree-of-freedom robot arm, a machine tool, a rotary robot arm and two conveyers; all are built with the Fischertechnik bricks. PLC is used for control programming. A human-machine-interface is also included in the system for monitoring. The students must learn essential knowledge and practice to integrate mechanical and electrical systems, to proceed system level design, and to implement a control program.

ASSESSMENT

We conducted a survey of our students at the end of the semester. Two categories of questions are asked, one about the course and the other about the achievement of the students. The questions are rated on a Likert scale of 1 (very negative) to 5 (very positive) and some significant outcomes will be discussed.

The course was highly appreciated (4.8) by the students. High rates were also assigned to the course creativity (4.35) and to the contents of the course (4.15). Not to our astonishment, Fischertechnik brick clearly attracts the students; all students positively agree (5) that it's both entertaining and educational.

Most of the students admitted that before the course they had little knowledge about most mechatronics elements (1.95). The responses pointed out that the course helped them learn and understand technology concepts better (4.45)

CONCLUSIONS

A new laboratory course in mechatronics has been developed for the undergraduates. Its uniqueness is the incorporation of the Fischertechnik bricks into the course to promote the engineering education. Other than just bookwork as in other classes, the extensive hands-on activities of this course have greatly attracted student's interest in learning the mechatronics. We hope that the ideas and resources presented in this paper will encourage more universities to develop similar courses.

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BETTER BY DESIGN: DEVELOPING TEACHING CONCEPTS THROUGH GROUP WORK

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ABSTRACT

The Department of Mechanical Engineering at the University of Sheffield currently has over 500 students registered on various courses, from the standard four year MEng in Mechanical Engineering course to Aerospace Engineering and Mechanical Engineering with Industrial Management for example. Whilst elements of design, innovation, marketing and manufacturing are taught throughout all four years of these courses, they are brought together in the 3rd year Group Design Project(GDP).

The GDP is a compulsory module with up to 100 students taking part. The assignment can be extremely varied from 'The Design of a Mars Roving Vehicle', (timed to coincide with the Beagle Mars landing attempt), 'The Design (and build) of a Micro-Air Vehicle', to the 'Development and Implementation of 'Green' Transport for Sheffield'. The students are split into teams of usually 6-8 students. However, how they organise themselves and the roles which they develop are part of the assessment and they are expected to use management and organisational behaviour theory in order to achieve this. Similarly through surgeries with outside clients such as EADS, South Yorkshire Police or Sheffield City Council and tutorials with staff, customer requirements are developed, expertise drawn and solutions produced. This culminates with the production of a group report and poster presentation day. During this day each group presents their poster to all members of staff in the Department, the customer(s) and other students. All students are also given a short interview about their roles and their personal understanding of the project and asked to reflect on their own contribution.

This paper outlines how the strands of innovation, marketing, design and manufacture are brought together in more detail using a recent GDP as a case study.

INTRODUCTION

In the past Group design projects had been run in conjunction with local industries in the South Yorkshire area. Due to an increase in student numbers and difficulties in sourcing suitable projects that gave student groups equal opportunities for learning, the module was re-structured. Over the past five years projects have been developed within the Department of Mechanical Engineering and these have ranged from the design of Mars landing vehicles to community transport schemes.

The responsibility for designing and organising the course over this period has been given to an individual member of the department's teaching staff. This responsibility moved on annually, with a different staff member 'chosen' at the start of each academic year. Whilst not regarded as a 'poison chalice' the amount of work involved in organising this module was particularly onerous when considered as an addition to an individual's normal teaching and research duty. The students also felt that they were not receiving the support and guidance they needed during the project.

A NEW APPROACH

The remit for the delivery of this module has recently been assigned to the Design, Manufacturing and Management Teaching Group (DMM Group) within the Department. This has enabled a novel and innovative approach to the development and delivery of the GDP.

Trowler *et al.* imply in their work(1) that the current practice of training individual academics to act as 'agents of change' to provide higher standards of teaching and learning within traditional higher education

Figure 1: Current wheelchair and roller-walkers

Figure 2: Reverse engineering exercise

establishment is fraught with difficulty. Reliance on individuals raises issues about how best practice is spread within the establishment and how the performance of that individual is assessed(2).

To address these shortcomings and to assess options for positive change the DMM decided to deliver the GDP as a 'team' effort. Within the DMM Group there are eight academics with a range of skills from industrial management practice and theory, to design methodologies and manufacturing processes. Members of the group are involved in high profile projects, such as the Advanced Manufacturing Research Centre, research into ergonomics and the encouragement of innovative and entrepreneurial skills in students (through the new Enterprise Lab – part of the White Rose Centre for Enterprise). This integrated knowledge base allows for the design of the project to cover a broad range of techniques and skills appropriate for the modern day engineering graduate.

The choice of project brief, design of content and scope was established through brainstorming sessions and detailed planning meetings where all DMM Group members were present and an integrated approach was taken making sure that all aspects of expertise were included. The chosen project for use as a case study here is that of the design and development of assistive walking technology and wheelchairs. The students were tasked to produce designs for wheelchairs and roller-walkers of the future, based on the technological advances and social change that could place in the next ten years. Typical current products are shown in **figure 1**.

MODULE STRUCTURE AND LEARNING OUTCOMES

As stated previously the module structure lecture content were developed during a number of brainstorming events held by the DMM group members. Delivery of the initial course material was carried out by outside experts, such as wheelchair users, carers and manufacturers. Workshops were run with wheelchairs, where students assessed disabled access in the Department and found out what it was like to be in a wheelchair. There was also a reverse engineering session where the students dismantled (and rebuilt!) wheelchairs and roller-walkers (see **figure 2**). Students were also given the opportunity to wear 'third-age suits to experience how it feels to be elderly (see **figure 3**). All DMM Group staff were involved in these exercises. More mainstream lectures were given on engineering issues such design standards, sustainability and all aspects of manufacturing

Figure 3: Third-age body suit use

technology by members of the DMM Group. **Table 1** shows the list of lecture material delivered.

The main drivers for this exercise were strong learning outcomes from the delivery of this module. It was felt that students should:

- be given the necessary skills and knowledge to understand how design is undertaken in the modern engineering environment
- understand how design interrelates with other strands of engineering expertise. For example they should also meet a market need at a required cost and be fit for purpose. Hence students are developing knowledge in understanding marketing techniques and the market in which they become involved. They also develop techniques such as design for manufacture
- have the confidence with the above skills such that their knowledge is transferred out into other parts of the course such as their final year projects.

It was felt that in previous years some of this focus had been lost and hence the re-design of the module in terms of content and delivery was aimed to reflect the outcomes as stated above.

A mentoring scheme was initiated during the project and each group was assigned a DMM staff member as their mentor. No fixed meetings were timetabled, it was down to the students to arrange meetings as they required them, to discuss their progress and seek advice.

Week	Day	Session	Session Leader	Topic
1	Mon	Lecture	GH/AY	Introduction to project, structure of course etc
	Thurs	Lecture	AY	Inclusive design and designing for the elderly
2	Mon	Lecture	Paul Griffiths	Disability Legislation
	Thurs	Lecture	Adam Williams	Introduction to Sunrise Medical
3	Mon	Surgery	All DMM	Reverse Engineering/Factory Visit/Data gathering
	Thurs	Surgery	All DMM	Reverse Engineering/Factory Visit/Data gathering
4	Mon	Lecture	AY	Review Session
	Thurs	Lecture	SRB/AY	Standards/Testing etc.
5	Mon	Lecture	GH/ERF	Marketing/segmentation/supply chain/cost
	Thurs	Lecture	RL/AH	Materials/sustainability
6	Mon	Lecture	WTG/MC	Design for manufacture/process and technology/cost
7	Mon	Surgery	AY/SRB	CAD/FEA
8	Mon	Surgery		CAD/FEA
12	Fri	Hand-in	All DMM	Hand-in for Group Report, Individual Report and Individual Poster
15	Wed	Assessment	All academic staff	Oral and Poster Presentations, Interviews

Table 1: Module lecture and workshop content

	Mark		
	Group	**Individual**	**Deadline**
1. Design Proposal	10		End Week 3
2. Gantt and organisation chart	5		End Week 3
3. Report (≤ 5000 words, ≤ 25 pages)		25*	End Week 12
4. Individual Poster (A3 size) and Portfolio (≤ 10 pages)		25	End Week 12
5. Presentation	15		Week 15
6. Group Poster (A0 size)	10		Week 15
7. Individual interview		10	Week 15
	40	60	

*Groups will be asked to agree and submit an 'individual effort factor' for each group member. (0 - 100%) The factors will be applied to the mark given for the group report and the resulting scores assigned to individual group members.

Table 2: Module assessment

Review sessions were timetabled where students were requested to reflect on their learning and understanding of the project to date and to feed back that experience to the DMM group.

MODULE ASSESSMENT

Details of the assessments, both group and individual are given in **table 2**. The earliest assessments, which included the design proposal and Gantt and organisational charts were very important in that they indicated whether the students had grasped the requirements of the project. Detailed feedback was given at this stage by mentors to ensure that the groups were progressing as they should be.

The remaining individual portfolio and poster and group report were handed in at the end of the project. The individual portfolio was a record of the specific work each student had carried out. For this they were encouraged to be reflective and use a range of different media to present the work.

The culmination of the module was the presentation day held in the last week of term. All academic staff were involved, which reflects the importance with which the Department views this module and further enhances the group ethic of delivery. In the morning each group was expected to give a 15 minute presentation to staff and their peers on the project outcomes. Following this session they were expected to answer technical questions about their design and processes undergone to meet the module requirements.

In the afternoon a poster presentation session was held where the output of each group of students was shown pictorially on an A0 sized colour poster (see **figure 4**).

Additionally, the individual A3 posters showing each student's contribution to their group's effort were displayed. Students were expected to answer questions on both posters (the

Figure 4: Poster session

larger poster reflecting the overall group effort) and to 'sell' their design to the 'customers'. These 'customers' were the sponsoring companies and members of the Departmental academic and technical staff.

Each student was also formally interviewed by the member of staff who had marked their portfolio and given the opportunity to discuss their individual contribution to the group effort.

Prizes were awarded by the sponsoring companies to the best posters and the best designs respectively.

FEEDBACK

Feedback from students was sought part way through the course and at the end. This enabled some actions to be taken to rectify identified issues while it could still help the students. Students provided good constructive criticism. Most of this was related to facilities and resources for the project, but they also highlighted the lack of customer involvement right the way through the project.

More access to the sponsors and a budget for prototype manufacture were arranged mid-way through the project to address this. Some groups were after access to rapid prototyping facilities which are now being put in place for future projects.

The students clearly enjoyed the project, typical feedback was that they:

- liked the fact this was a real problem they were working on that allowed them to apply the knowledge they had been accumulating over the first and that it gave them an opportunity to do some 'hands-on' engineering.
- also thought it was good that it incorporated project and team management and that it was competitive!
- liked being left to run the project as they saw fit, collecting the information they needed and getting on with it.
- thought the mentoring system was useful as it made it more personal and they could get advice or help more readily than if one person was looking after all the groups as had happened previously.

From a staffing point of view it worked well as there was no big burden on any particular member of staff. There was flexibility in when sessions ad lectures were arranged which made things much easier.

CONCLUSIONS

The case study described was considered to be more successful than those run in recent years. This conclusion was drawn because of a number of a number of factors:

- Focused learning outcomes based on basic engineering design issues were introduced
- There was a strong team ethic within DMM teaching group in the design and delivery of the course
- Positive feedback was received from staff across the Department and participating students.

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STUDENTS' PERCEPTION OF DESIGN IN TECHNOLOGY

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OBSERVATIONS

In Malta, all post secondary university bound students are encouraged to familiarize themselves with different subject areas and learning styles in the attempt to extend the breadth of knowledge of all learners and elevate the students' attitude toward lifelong education into a more holistic approach (Giordmaina[1], NMC[2], EuroEducation[3]). The fields covered can be classified under the following headings: (a) Democracy and Social behavior, (b) Artistic and Aesthetic values (c) Scientific and Technical values (d) The environment and sustainability (Giordmaina[4]). Collectively, the areas mentioned above are examined under the chosen title 'Systems of Knowledge' (SOK). The artistic and technical branches differ from the others in their form of assessment since this also includes the design and implementation of a project involving use of tools and material formation apart from a written examination. The choice of the theme for the project is left entirely to the student, and the artifact must eventually be presented to Matriculation and Secondary Education Certificate (MATSEC) representatives together with a written report.

Over the past fifteen years approximately two thousand students per year followed this pre-entry requirement into the University of Malta. Over the years it was observed that the least popular area with students, teachers and parents was always the technical project because unfortunately many put their focus on the end product rather than the learning process experienced by the students whilst designing and implementing the project (Pulé C.[5]). The project's unpopularity was such as to make University authorities review the validity of this particular mode of assessment. The inclusion of the design and implementation of the technical project is currently intended for the student to pass through the following processes: (a) A written analysis of how a decision on the choice of project was made and research on the technology (not history) within the chosen field. (Rationale behind the project). (b) A clear, concise written description and analysis showing the understanding of hidden scientific principles, sequences, logic of static and dynamic processes within the project. (c) Production of symbolic and clearly written representations of project performance through tables, sketches, geometrical figures, graphs, mathematical modeling and even computer simulations if possible. (d) The implementation of the artifact through choice of physical materials and construction methods. (e) Clear written documentation of the testing procedures, relating the parameters that affect the system function within the project. (f) Present any suggestions for improvement of performance and comment on reliability, and maintenance schedules. These processes were also highlighted as being essential for the engineering design process by (Lewis[6]). Examiners appointed by MATSEC vet the students by interview to check the depth of understanding of the analysis conducted and the final grade is awarded according to the performance of the student during the interview, rather than only on the quality of the artifact or the written report accompanying it.

By sharing assessment experiences with some experienced examiners and being appointed moderator for the technical projects herself while also teaching Design and Technology at the University of Malta, the author was able to observe the following: (a) Many students find extreme difficulty in deciding what project they can do when left at liberty to do so. (b) Students, teachers and parents alike expect that the majority of the marks are allotted to the actual 'manual work' involved in the construction of the project and diminish, or are not even aware of the importance of planning, scientific analysis, testing and suggestions for modifications. (c) A majority of students within the 17-19 age bracket who graduate from secondary schools are not able to handle abstract concepts such as the rate of change of a function with respect to a variable in space or time or any other variable. Indeed, the most popular projects are of a mechanical nature where some scientific principles can be visually tested or verified. (d) Most students prefer to handle technology from an operational point of view only. In response to a question: ‘How does it work?’, most students answer on how one should operate the artifact, or what the artifact does rather than mentioning any scientific principles involved in the functioning of it. Pulé(5) reports that ‘A few students do go into and so close to the realm and depth of technology, but most are still ‘I got some wood, hammered a nail in it to attach it to the other side, gave the whole project a coat of paint and then varnished it all over to give it a nice colour – see this switch – when I switch it on this light goes on and the motor goes around to make some wind!’ . . . and that is technology for some teachers and some students!’ (e) Students are unaware of the strong links between subject areas like mathematics and the sciences. Many students are unaware that processes can be accurately described mathematically and not only verbally or by the use of illustrations.

AIM

The main aim of this contribution is to try to identify why students experience the above mentioned difficulties especially when encountered with a technical project and if anything may be done to overcome them. It is strongly felt that when students encounter the word ‘design’, they equate the process with a change in the outer shape of an object. Design in this sense is very much promoted in many forms in every day life, for example in the fashion industry, some garments are ‘designed’ for glamour much more than for comfort. Advertisements for technological gadgets put a much greater emphasis on their visual aspect and ergonomics rather than the myriad of functions they can offer. From a marketing point of view this can be perfectly justifiable. However, from an educational point of view it is less than acceptable and its consequences include having students who treat the environment around them as if it were a black box without ever appreciating or questioning the scientific wonders contained within(6). The phenomenon of underestimation is commonly observed in students learning technical drawing, for example. Students who still use relatively old fashioned tools like the T-square, protractor and set square for drawing develop better motor skills and infinitely better visualization and imaginative capacity than students who use software drawing packages that automatically supply an animation of the three dimensional object they are to draw (Dougiamas[7]). The students rarely take the initiative to question how the click and drag action on their mouse is translating into a visual image on their screen. They tend to take it for granted and little do they inquire about the amount of training, time and effort a human programmer has put into the software design to make it straightforward for them to operate. This point of view must not be interpreted as a depreciation of modern educational tools, nevertheless, when using these tools, a teacher must be aware and cautious of any advantages and disadvantages that may come with the chosen style of teaching. Students may be attaching a superficial meaning to the process of ‘design’ due to the following reasons: (a) Their own cognitive abilities are not sufficiently developed as to enable them to delve deeper than the visual strata of the design of an artifact, or their own knowledge may be very limited. (b) Their experience of past training in the design process involved only the most superficial layers, and therefore they are following suit. (c) The design process is still being promoted as a superficial practice by our education system and therefore presents a biased approach to students (Jones[8]). This is strongly suggested in Pulé(5) when he writes that ‘teachers handling technology in Systems of Knowledge are in general not qualified to depict what is really required. Most still represent technology as craft or as a literary or historic exercise. Most teachers do their best but the truth is that they are not technically qualified and the spark of technology is still missing’.

OBSERVATIONS MADE DURING PROJECT DESIGN AND IMPLEMENTATION

This section gives some detailed examples on the misconceptions about certain aspects of technology. It is noted that the electrical field suffers the greatest misconceptions when compared with other fields. Maybe this occurs because the visual aspect is very limited in this area and the design of electronic projects involves abstract thinking and the use of mathematical calculations. When asked to design an electronic circuit, students usually request to be given the circuit diagram, or else ask about the web site from where it can be readily downloaded from the internet. Their conception of design is the actual physical laying out of components on a strip board or printed circuit board but not of the actual electronic function of the circuit. Many students also assume that the enclosure of an electronic project is part of the electronic design and it is noted that quite a large percentage of students dedicate much more time and effort in the planning of the container rather than the actual electronic design. Sadly enough, some teachers fall into this trap of misconception(8) also and incorrectly promote electronic design as the mechanical and aesthetic design of a container (Cross[9]). Even after a strip board layout is complete, when students are asked to perform a check of the product, their attention is usually attracted towards the aesthetically pleasing arrangement of electronic components, rather than for example, the quality of their soldering joints or the positioning of components to optimize heat dissipation within the container, or for easy maintenance. It is therefore noted that students fail to appreciate anything that is not visually apparent. Even after the functional concepts are formally taught, it is observed that students find it very difficult to adapt into a new regime of thinking skills and are very slow in starting to adopt these skills in which they are less confident. Many times they resume to their old habits even after taking a formal course where recognizing and practicing of functional skills is promoted.

TOPIC DISCUSSIONS DURING INTERVIEWS

A very common misconception occurs in projects involving electromagnetic effects. Students find it extremely complicated to visualize the cutting of magnetic flux to generate an electromotive force in a coil, for instance. When presented with a coil and a bar magnet and asked to show how an electromotive force is generated during their interview, most students position the magnet at one end of the coil and parallel to the coil's long axis. Holding it fixed in the middle of the coil's cross sectional area, they usually rotate the magnet about its long axis and expect to generate an electromotive force across the coil. Some students move the magnet within the coil's cross sectional area without ever crossing its boundaries, again hoping to generate an electromotive force across the coil.

The application of scientific principles and calculations in mechanical projects seem to be only slightly more apparent than in electronic projects. Students designing a windmill, for example, usually choose to follow cultural traditions and just copy the external shape of the machine without observing such details as the shape of the blades. It is sometimes amusing on one hand, but preoccupying on another when students connect an electrical motor to the main shaft and turn the windmill in opposition to the direction it should turn by the wind! When, during an interview, students are asked to describe how and where regions of high and low pressure develop around the cross section of one of the blades of the windmill, they usually just argue that 'a windmill turns because the wind blows on it'! With projects involving structures such as cranes, students rarely conduct tests on their load bearing properties or on their stability. They usually have great difficulty identifying components of a simple framework structure that are in tension or in compression when this is required of them during an interview. In projects involving heat transfer students may choose the wrong type of materials for insulation because they do not fully understand the concepts of conduction. They may position heat sources incorrectly or design solar heating systems with the positions of the hot and cold terminals interchanged due to a false understanding of the concept of convection. When designing a bimetallic strip, some pupils expected it to flex without securing both extremities of the two materials with diverse expansion properties, clearly showing that they failed to accurately understand why the observed effect is the curving of the strip. The principle of buoyancy is also greatly misunderstood by many. When asked if metals can be made to float, a student's first reaction is usually that of perplexity. On capturing their attention, during an interview, that many ships are made of metal, students find it hard to accept that it is not the light air inside the ship that makes it float.

Mathematics in general, is viewed by many students to be a subject with very limited applications. Students do not see any link between mathematics and the design of a technical project and many times therefore present their project as craftwork with no accompanying analysis or testing. For example, one student presenting a parabolic reflector as a heat concentrating device was not aware that the locus of a parabola may be accurately expressed by a mathematical equation. Her design of the parabolic locus followed only what she could observe visually and hence her tracing of the shape left much to be desired. Simple calculations such as finding the angular velocity of a driven gearwheel, given the velocity of the driver wheel together with the number of teeth of both wheels proves to be tasking for many students. Interpreting mathematical answers is also very difficult for students sometimes. When dealing with electrical current for example, a negative answer may simply mean that current is flowing in a reverse direction, however, many students, especially those not familiar with physics at an A-level standard, interpret this as a wrong answer! An intuitive feel for numerical quantities(9) is also lacking from students and this indicates the lack of technical and scientific practice they get from the current educational system. This is mirrored by the students' inability to check themselves when performing calculations and verifying that numerical answers make sense, for example, that it is very unlikely that a person weighs 10,000 Newtons in real life and normal conditions! Overall, the general trend adopted for all projects is that 'if it seems to work it should not be touched!'. Machines are not investigated on issues such as efficiency, power dissipation and ease of operation or maintenance. For electronic projects, for example, once some light emitting diode used as a visual indicator operates, then students display no initiative to analyze their circuits for measurements of currents, voltages or operating conditions of active devices. Indeed cases were encountered during interviews where, a circuit worked only for a couple of minutes due to its exaggeratedly miscalculated power requirements and the student attributed this failure to her own incapability of handling a soldering iron. The true reason for the project's failure was that there was absolutely no design in her circuit!

For mechanical projects, cases were encountered during interviews, whereby students believe that loosely fitted joints on a model crane would bear heavy loads without collapsing or would offer stability. No factual tests where conducted and the student displayed a substantial measure of awe when his project was unable to bear very light loads such as that offered by some stationary items. One very preoccupying issue is that students with limited knowledge and initiative attribute the failure of their projects entirely to their own personal self and create a viscous circle of failure and lack of self-confidence (Hendley[10]). This is highly detrimental to the person's sense of worth and seriously affects the way these students perceive not only technology and the design of artifacts, but also their perspective on lifelong education in general. It also has a high impact on their choice of future careers and their contribution to society.

SUGGESTIONS FOR THE RECTIFICATION OF GENERAL MISCONCEPTIONS

It is felt that the generic reason for the budding of these misconceptions in the scientific, mathematical and technological fields is the lack of applicability of these fields perceived by the typical student(10). Pupils have a tendency to disassociate what they learn at school and the environment around them(8). Maybe, the delivery of scientific, mathematical and technological knowledge at school promotes such detachment due to the lack of sufficient practical sessions backing up these subjects. This may be one reason why abstract concepts are difficult to grasp. Therefore, the first step that our educational system may take is to try and aid the transition toward the abstract into being a smoother one. Indeed, the need for stronger links between mathematics, science and technology is emphasized by(6). This may be achieved by explaining what is invisible by the use of visible media that are familiar to students (Howe[11], Murray[12]). Some concepts in mathematics may be explained by exploiting an affiliation with drawing techniques such as shading. Functions and related processes may be visualized as being artistic paintings and the nature of the painting technique may be related to important mathematical processes such as differentiation as a ‘rate of change’. **Figure 1(a)-(d)** show images generated by transforming the given respective matrices into a grayscale illustration using the Matlab software package (Matlab[13]) command lines shown on the left of each subfigure. The numbers in the matrix describe a two dimensional function which can easily be visualized in the images. Functions may take infinite shapes and forms and only simplistic examples are shown here. **Figure 1(a),(b)** display a function changing abruptly along the x axis and y axis respectively. **Figure 1(c)**, illustrates a two dimensional constant function and **Figure 1(d)** a linearly variable function. It is quite straightforward for students to accept that values in the matrix correspond to shading levels in the respective figures. Once, pupils have established this connection, it is then easy to step into the abstract by defining the matrices to represent temperatures or pressures in a medium, for instance. The process of ‘rate of change’ of a function with respect to a variable in space may be initiated by performing the difference in between rows or columns of the matrix as is required. **Figure 1(e),(f)** show the images generated when the neighbouring columns or rows respectively of the matrices in subplot (a),(b) are subtracted from each other. This is loosely equivalent to taking the derivative of the function with respect to the x and y direction respectively. Thus regions of change within the function are highlighted while constant areas are also easily identified due to the visual impact of the generated images in subplots (e),(f). **Figure 1(g),(h)** depict the derivative images from subplots (c),(d) respectively, where the derivative of a constant and also that of a linear function take form in a clearly presented visual technique. Once the student is confident in his/her understanding of ‘rate of change’ and is capable of identifying and extracting this information from a simple plot, he/she should feel comfortable with more complex functions both in the real and the abstract world. Other real world visual examples could include the extraction of higher derivatives of data involving polycolour scenarios, unsymmetry and distortion techniques employed in visual media. By conducting interviews with students during the SOK moderation for the technical projects it is observed that once students are successful in distinguishing the links between the visual and the abstract in such simple

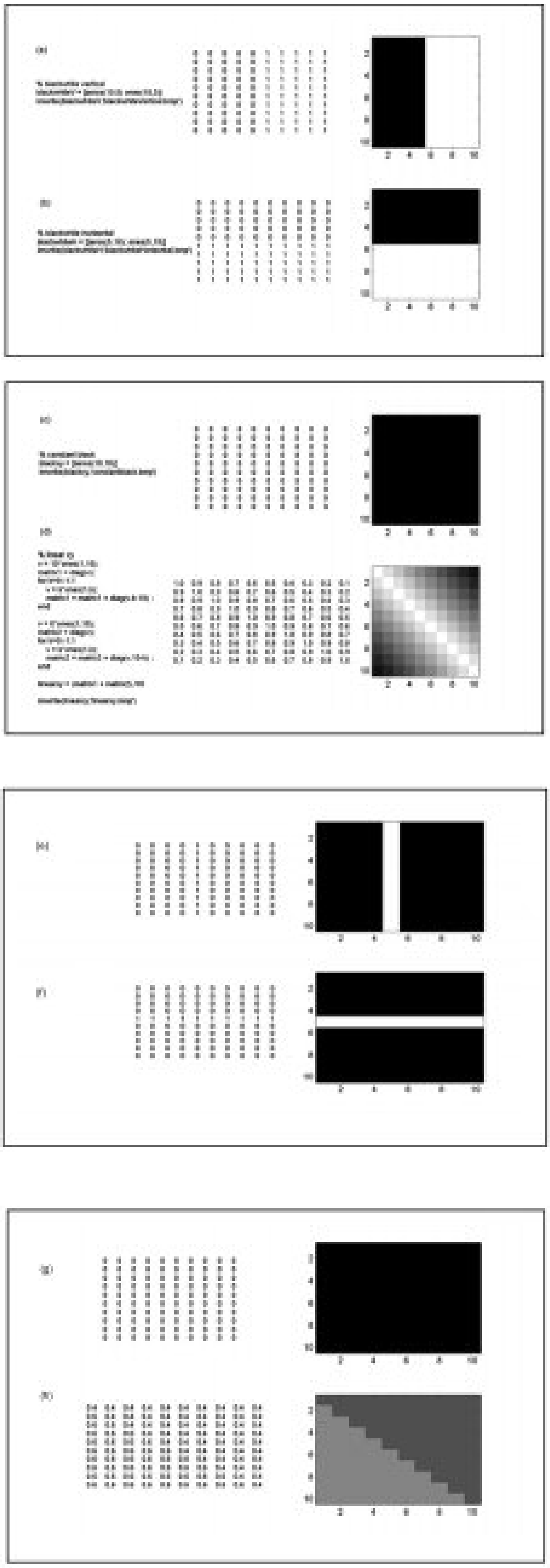

Figure 1: Simple functions and their rate of change

examples, their powers of cognition increase tremendously and they take a rapid stride over the hill of lack of self-confidence. Thus, it is not necessary to find methodologies that reduce all abstract concepts into more visual ones. This is only necessary as a short but highly effective induction period. Once this is over, it is important to continue feeding and training the student with gradually increasing complex abstract concepts so that they can continue feeling comfortable.

In mathematics, science and technology many times transformations are used to explain or work with a concept more conveniently. For example, the Laplace transform as used in control engineering may be regarded as a convenient way to handle a system that is difficult to solve in the time domain, but more readily manageable in the Laplace domain. The idea of domains or worlds each with their own different atmospheres and rules may be initiated from a very early age in students by encouraging them to be creative and invent new worlds where to live. This may be taken as far as considering the use of fables and storytelling. A given personality may be made to delve into the planet of spherical coordinates rather than that of cartesian coordinates, for example, and immediately, his mode of transporting himself is affected. Also, one could try to imagine what life would be like in worlds of different dimensions. Such a methodology used with young students may be the key to paving the way for later requirements in technological education. It is therefore important to stress the coordination of teachers from all levels of education. This also involves the promoting of activities where the design of shape and aesthetics is not always the prime motif of an exercise. It is essential that from an early age, students are trained to look beyond what lies on the surface of anything they encounter during their life.

RESEARCH POSSIBILITIES

Future research could focus on how to develop effective teaching strategies for specific topics where students find most difficulty, such as those mentioned in this paper. It could also target the development of better assessment methods that ensure a fair and just measurement of the student's abilities (Banks[14]).

CONCLUSIONS

This article has highlighted some of the major misconceptions made by pre-university students, encountered in the field of design in technology and also suggested some reasons for their presence. It has also attempted to suggest some general strategies whereby abstract concepts may be made more visible to students to aid their understanding of the hidden functional aspect of technical design. This technique emphasizes the links between mathematics and technology while using a purely artistic skill such as simple sketching as a medium to approach the students.

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