Role Modelling Teamwork Through Teaching of Mechanical Design

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***Abstract**: In this paper results of years of experimenting in team teaching of mechanical design at QUT are discussed. Multi-skilled team of academics, practising engineers and consultants put together their knowledge, experience and talent to the benefit of students enabling them to acquire the whole range of generic skills while studying mechanical design.*

***Keywords**: mechanical design, role modelling, team teaching*

Introduction

Mechanical design is regarded by many as a backbone of Mechanical Engineering. Study of mechanical design requires a solid foundation in the basic sciences and fundamental engineering units such as Mathematics, Dynamics, Mechanics of Solids, Applied Mechanics and Materials study. Students also get an insight in some specific engineering areas such as Fluid Mechanics, Thermodynamics, Industrial Automation, and Manufacturing processes. Mechanical design brings together all these units and this makes it one of the most difficult and interesting subjects to teach.

The structure of Mechanical Design units varies from university to university. However, the following base prescription seems to be common - Design procedures, Concept development in design, Materials Selection in Design, Design of mechanical components, Machinery Design, and the Design project(s). At some universities these units are supplemented with elective units on Computer-aided Design, Design for manufacture, Tribology, and Design Optimisation. Machine Reliability and Failure Analysis, as well as Occupational Health and Safety are not normally taught in design. Authors visiting other universities and communicating with colleagues identified some problems with teaching mechanical design that are common for many Australian universities. They are as follows:

- Engineering Drawing is in most cases taught for 1 to 2 weeks in the introductory unit such as Professional Studies and as a result students complete design units having poor hand drawing skills. On the contrary, in India and republics of former USSR engineering drawing is taught for several semesters.
- Mechanical Design units, including Computer-aided Design, are self-contained and students do not see direct relationship between them.

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- Design projects in most cases are individual and do not encourage teamwork, or if a project is a team-project, it does not have individual component and everybody gets the same mark.
- Students do no get an understanding of a system approach to design and clear understanding of the life cycle of a product.
- The limited time-frame available forces design lecturers to skip or teach superficially some important topics, such as tolerancing and surface roughness. As a result, students do not know how to select these parameters properly.
- Engineering creativity is not systematically taught – at best lecturers mention Brainstorming and Lateral Thinking, being unaware of the existence of such powerful problem solving methodologies as the Theory of Inventive Problem Solving (TRIZ).
- Students lack hands-on experience – in many engineering schools, students completing two or three design units have not seen real gearboxes, only transparencies or illustrations in textbooks.
- Design for manufacturability and maintenance aspects of design are normally overlooked. Machine condition monitoring is taught at postgraduate level or in elective unit, such as Industrial noise and vibrations, with no relation to design.

As a result of these shortcomings, development of generic skills of students studying mechanical design becomes hard to achieve. New approaches to teaching of mechanical design are required. In the School of Mechanical, Manufacturing and Medical Engineering (SMMME) at QUT, a new structure of mechanical design units has been developed and new teaching approaches have been introduced (including team teaching) that overcomes most of shortcomings discussed above.

Structure of Mechanical Design Units at QUT

In the School of MMME at QUT mechanical design is taught in three core units:

- Fundamentals of Mechanical Design.
- Design of Mechanical Components.
- Design and Maintenance of Machinery.

The content of these units is as follows:

Fundamentals of Mechanical Design:
Introduction to mechanical design; System and functional approach to design; Design for sustainability and universal design; Concept development in design; Best concept selection; Review of creative problem solving methodologies; The Theory of Inventive Problem Solving (Ideation / TRIZ methodology); Detail design, fits and limits, surface roughness; Load analysis in design, Free-body diagram (FBD), computational scheme in design; Modelling and simulation in design; Design for strength (review of stress computations for different load combinations); Determination of forces in gear trains; Shaft design code AS1403; Rolling bearing selection; Sliding bearing design.
An essential part of this unit is Warman Design and Build Competition (run by the IEAust on an annual basis) where students in teams of four design and construct a device to carry out a certain function. Students also systematically study AutoCAD and submit a hand-drawn assignment for a part from a given assembly. Significant emphasis in this unit is put on systematic teaching of engineering creativity and encouragement of teamwork (Warman Competition and hand-drawing assignment when an assembly drawing is given for 2 to 5 students with necessity to produce individual part drawing).

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Design of Mechanical Components:
Materials selection for machine components; Fasteners; Shafts and associated parts; Gear trains design calculations; Drives with flexible elements; Cam design; Springs; Fundamentals of lubrication; Frames and housings, machine components relationship; Clutches couplings and brakes; Design for manufacturability.

An essential part of this unit is a gearbox design project that students carry out in a team of three. Using gearbox selection software from Bonfiglioli Reduttori (the Italian gearbox manufacturer), they select as a team the configuration of a drive for a given machine, and then for individual operating conditions (individual for every student) they design a gearbox. They also systematically study solid modelling software (Solidworks) and produce a solid model of the gearbox.

Design and Maintenance of Machinery:
Design of equipment for specific application (mining, chemical, food processing equipment, materials handling, etc.); Fundamentals of friction and wear; Optimisation in design; Design for reliability, risk assessment and failure prediction, the use of fracture mechanics for reliability analysis; Machine condition monitoring; Styling and ergonomics; Intellectual property; Quality assurance in design; Engineering ethics.

An essential part of this unit is a project on the development of lubricating system, which is an extension to the gearbox design project that students carry out in the same teams of three. To facilitate students' study several interactive software packages are used. They are as follows:

- SKF bearing selection software with recommendations on lubrication.
- SEW Eurodrive gearbox selection software with recommendations on lubrication.
- "i-Learn" software for interactive learning of vibration and machine condition monitoring (developed by Mebius Ltd). It has several modules including lectures, transmission modelling, signal processing, and case studies on machinery failure.
- Innovative WorkBench software based on TRIZ methodology for creative solving of engineering problems (developed by the Ideation International Inc., USA, http:\\www.ideationtriz.com).

These software packages are available for students in the Design Studio during design tutorials and in computer classes.

The Design Studio has been developed to carry out tutorial and practical sessions. In the Design Studio numerous gearboxes are put on display (some of them are sectioned), demonstration and test rigs built through final year projects (see figures 1, 2, 3). Students have an opportunity to combine theoretical studies with practical exercises and gain hands-on experience working with modern real equipment, such as gearboxes. Some of the demonstration rigs and mechanical components have been donated to the School by private companies, e.g. BMW Australia, SEW Eurodrive Ltd., MEN Australia Ltd and ETA Ltd.

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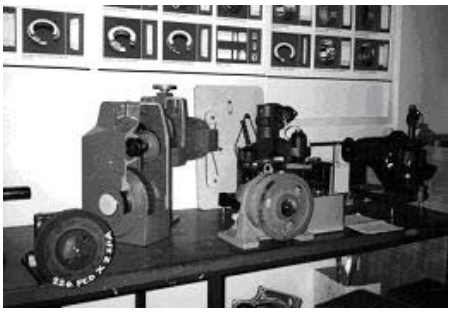

Figure 1: Sectioned gearboxes

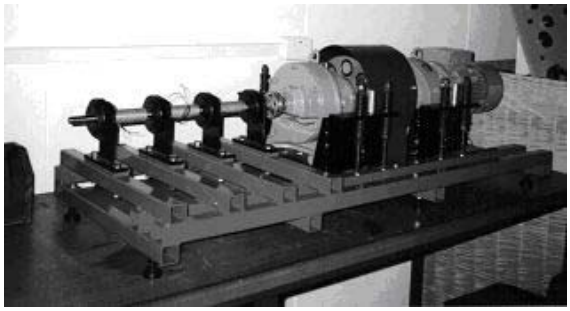

Figure 2: Cyclodrive test rig

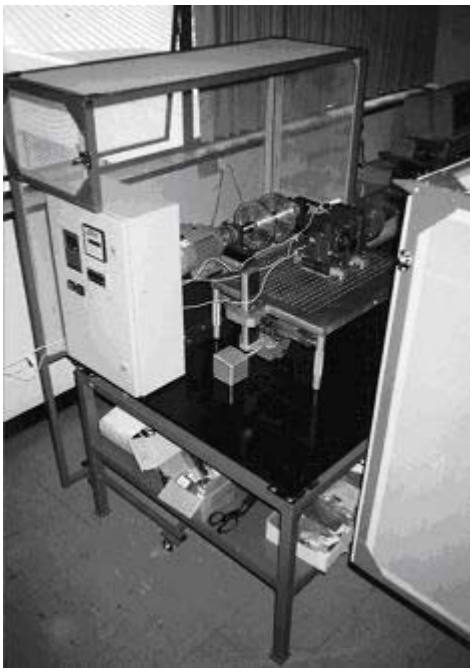

Figure 3: Machinery Fault Simulator for modelling of mechanical faults

Figure 4: Galleries of famous engineers and scientists (general, above and tribologists, below)

The galleries of famous engineers and scientists depicted in figure 4 (one general, and another one in the area of tribology) give to students insight in the history of engineering – how different engineering and design rules were introduced in engineering practice, and helps them to feel proud for their profession.

These teaching facilities and teaching approaches enabled us to overcome the main difficulty of teaching of mechanical design – how to accommodate a large amount of material into a limited timeframe, and also achieve a high degree of development of almost all 10 generic skills specified by the Institution of Engineers, Australia. Students wanting to continue their study in some specific areas have an opportunity to take elective units, such as Fundamental of tribology, Industrial noise and vibrations, Process system design, Design for manufacturing and Engineering asset management and maintenance.

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Team Role Modelling

As has been highlighted previously, mechanical design brings together knowledge from numerous subjects and requires multi-skilled lecturing and tutoring. It is almost impossible to find any one person with expertise in all areas involved. At the School of MMME a decision has been taken to arrange team teaching of mechanical design. With a strong emphasis on students' teamwork, it enabled team role modelling. The following academic staff and part-time tutors from industry are engaged in teaching:

The team leader, Senior lecturer in Mechanical design is leading the team. He delivers a major part of all three design units. He is a professional inventor with 17 patented inventions and practical design experience. He is the leading TRIZ expert in Australia with research interests in drive train dynamics, mathematical and computer modelling of machines, vibration analysis, engineering creativity, and equipment reliability and failure analysis. He is unit coordinator for all three design units.

The second team member is an expert in tribology and its environmental application. He delivers modules on lubrication, fundamentals of friction and wear, and supervises a lubrication project in the third design unit. He also delivers an elective unit Tribology. He has been the President of the Queensland Division of the Institution of Engineers, Australia (2002) and brings his knowledge of the IEAust structures and legislation, including the Code of Ethics.

The third team member with expertise in materials study delivers a module on the use of fracture mechanics in machine reliability analysis and advises project students on materials selection and heat treatment. Other team members having expertise in manufacturing, advise project students on fabrication methods.

The team also consists of part-time lecturers and tutors from industry:

Director of the CADfx Ltd. – a company specialising in computer-aided design. He is a highly experienced engineer in solid modelling, and delivers SolidWorks classes as part of the second design unit.

Chief Safety Engineer with the Division of Workplace Health and Safety, Department of Industrial Relations, Queensland Government. He is experienced consulting engineer with expertise in mechanical design, OH&S, risk analysis and industrial accident analysis. He delivers a module on OH&S, risk analysis and also is tutoring in two design units.

Director of KJB Engineering Ltd., specialising in product design and manufacturing, and microwave technology. He is practising consultant with extensive practical experience in automotive industry in Germany. He is tutoring in the first and the second design units.

Other part-time tutors are engaged on a casual basis for running AutoCAD classes and tutoring when necessary.
The formation of this multi-skilled team of highly experienced academics and practising engineers enabled students to see teamwork in action and get expert advise on different aspects of mechanical design and on design projects. This also ensures the highest possible level of teaching of mechanical design at the School.

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Encouraging Students Teamwork

The teaching of mechanical design at QUT is arranged in such a way that encourages student teamwork. In the first design unit fundamentals of teamwork are systematically taught with emphasis on communication, decision-making and team self-management. Several team exercises and team projects are built in all three design units.

The first design unit: *Fundamentals of Mechanical Deign:*

Students prepare an individual part drawing from an assembly drawing given for 3 to 5 students. This encourages them to communicate to find out dimensions, fits and limits for mating parts. The part drawing they prepare individually taking design decision on the drawing format, scaling factor, number of views and sections, etc.

Students participate in three brainstorming sessions in teams of 6 to 7 students and then present as a team ideas generated.

Students in teams of four participate in Warman Design and Build competition.

The second design unit: *Design of Mechanical Components:*

Students in teams of three work on the gearbox design project. Part of the project (selection of the gearbox configuration) is carried out as a team, then design calculations are performed individually for different operating conditions. They also develop individually a solid model of the gearbox.

Two laboratory sessions are carried out in teams of 4 to 5 students.

The third design unit: *Design and Maintenance of Machinery:*

Students carry out a design project on lubrication, which is an extension of the gearbox project. Students work in the same teams of three with individual operating conditions taken from the previous project.

A combination of teamwork with necessity to take individual design decisions facilitates the development of teamwork skills, communication skills and life-long learning through the use of different teaching and learning resources. Continuous communication with the design teaching team, which includes academics and practising engineers, gives to students a vivid example of teamwork in action and encouragement to achieve high results. Over the last three years the failure rate in mechanical design units has been significantly lower than in other engineering units.

Teaching and Learning Resources

A variety of teaching and learning resources have been developed and made available for students to support their study and teamwork. They include:

- Course notes for all three design units that are available from the Design Web-site and until 2002 were available in hard copy from QUT bookshop [1].
- Course notes for the module on Fundamentals of Friction and Wear [2] that are available from the Design Web-site.

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- A book on fundamentals of lubrication [3], is available from QUT bookshop.
- A handbook on solving problems with TRIZ [4]. Five copies of the book are available from QUT library. The first part of the book with problem statements with permission of the Ideation Int. Inc. has been placed on the Design Web-site.
- The Web site of the Department of Industrial Relations of Queensland Government with standards on OH&S and Risk Analysis [5].
- Design standards [6] in hard copy that are available for students in the Design Studio.
- Standards on technical drawing [7] in hard copy that are available for students in the Design Studio.
- Access to Australian Standards online from the Design Studio.
- Hard copies of catalogues from gearbox manufactures as well as access on-line to their electronic catalogues.
- Tutorials on different design topics with solved examples that are available for students from the Design Web-site.
- The Design Studio with numerous demonstration and test rigs, posters and networked computers that provide access to on-line teaching facilities.
- Different textbooks on mechanical design are available from QUT library.
- Numerous specialised interactive software packages to assist students with group projects and individual study. In particular:
  - Innovative WorkBench for creative problem solving.
  - "i - Learn" for interactive learning of vibrations and machine condition monitoring.
  - Genius software from Bonfiblioli Reduttori on gearbox selection.
  - SEW Application from SEW Eurodrive on gearbox selection.
  - SKF software on bearing selection.
  - Exact software package on maintenance systems.

These teaching and learning resources provide excellent facilities for students' learning in groups and individually.

How the New Teaching Arrangement Helps to Develop Generic Skills

New teaching arrangements, teaching and learning resources developed and introduced for teaching of mechanical design at QUT, facilitate the development of all generic skills specified by the Institution of Engineers, Australia. In particular:

(a) Ability to apply knowledge of basic **Science and Engineering fundamentals.** Students have the opportunity to see how basic sciences and engineering fundamentals are integrated in mechanical design.

(b) Ability to **communicate effectively**, not only with engineers but also with the community at large.
One of the objectives of design is to develop products that satisfy people's needs individually and in mass. This message is conveyed to students through all design

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units. They also communicate with companies and suppliers working on design and final year projects and during work experience.

(c) In-depth **technical competence** in at least one engineering discipline.
Taking consecutively three design units students gradually evolve from understanding of basic design procedures to advanced design with the use of advanced design tools, such as solid modelling, and put to use through design projects.

(d) Ability to undertake **problem** identification, formulation and **solution.**
Engineering creativity is systematically taught in design units, including problem formulation and advanced methods of creative solving of engineering problems, which are put to use through design projects.

(e) Ability to utilise a **systems approach** to design and operational performance.
A system approach to design is systematically taught in the first design unit and strengthen through continuing design projects when students have an opportunity to observe the whole life cycle of a product and different aspects of a product development, commissioning and maintenance.

(f) Ability to function effectively as an individual and in multi-disciplinary and multicultural teams, with the capacity **to be leader or manager** as well as an effective team member.
This generic skill is developed through a series of team design projects, team exercises, as well as through systematic teaching of team-building and leadership issues in the first design unit.

(g) Understanding of social, cultural, global and environmental responsibilities of professional engineers, and the need for **sustainable development.**
These issues are systematically taught in all design units and emphasised in design projects, e.g. selection of environmentally friendly lubricants.

(h) Understanding of the principles of **sustainable design** and development.
This issue is systematically taught and especially emphasised in value analysis (carrying out a function at a minimum cost) and in material selection.

(i) Understanding of and commitment to **professional and ethical responsibilities.**
This issue is highlighted through all design units and specifically discussed in the third unit. The Code of Ethics of the Institution of Engineers, Australia is placed at the Design Web-site and in Design course notes.

(j) Expectation and capacity to undertake **life-long learning.**
A combination of teaching approaches, teaching and learning resources for mechanical design encourages students to find information and learn themselves. It is emphasised through all design units that design problems do not have one unique answer – what is good solution today may well become an unsatisfactory solution tomorrow. Students strengthen their understanding of necessity of continuous looking for better solutions and continuous life-long learning.

To assess generic skills gained while studying mechanical design, the following approaches have been used:

- Formal and informal assessment that include written assignments, oral presentations (individual and in teams), poster presentations.
- Student evaluation of units (SEU) and student evaluation of teaching (SET).
- Feedback from students (oral, E-mails and surveys).
- Feedback from employers on students working part-time and full-time after graduation.
- Feedback from the Students Liaison Committee.

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- Feedback from final year project supervisors and industry partners on CEED projects.

From the Second Semester of year 2003 a new assessment system based on Students' Capability Profile (SCP) will be introduced in the third design unit, as well as methods of teamwork assessment outlined in [8], such as "Johari Window", team behaviours and roles.

Conclusions

In this paper role modelling teamwork through teaching of Mechanical Design at QUT has been discussed. It has been demonstrated that:

- Team teaching of Mechanical Design brings together academics and practising engineers in multi-skilled team for the benefits of students.
- Team projects when students carry out a part of a project as a team and another part individually enables them to strengthen their skills in teamwork and work as an individual.
- Continuing projects through two design units enable students to understand different aspects of design, the life cycle of a product and system approach to design.
- Communication with the design teaching team, which includes academics and practising engineers, gives to students a vivid example of teamwork in action and encouragement to achieve high results.
- Over the last three years failure rate in mechanical design units has been significantly lower than in other engineering units.
- New teaching approaches introduced in teaching of mechanical design at QUT allowed the achievement of high level of development of generic skills.

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