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Teaching Tribology and Maintenance-related Subjects: a Hands-on Focus

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Abstract

In this paper different aspects of teaching tribology and maintenance-related subjects with a hands-on focus at Queensland University of Technology (QUT) are presented and discussed. As part of the study, a combination of data from core units, such as engineering design units, and elective units, was used, in addition to laboratory experiments, real-life projects, interactive software packages and industry visits. The mechanical engineering curriculum structure used at QUT, consisting of the main specialization (first major) and the second specialization (second major), is also discussed with specific emphasis on the teaching of tribology and maintenance-related subjects. To evaluate students' satisfaction with the novel teaching approaches used, tailored questionnaires were used as well as QUT's online learning experience survey (LEX). Statistical results of these surveys are presented and discussed. In summary, these showed that students overwhelmingly support the hands-on and practical focus in teaching tribology and maintenance-related subjects and that the teaching approaches used shorten the learning curve and make students better prepared for integration in the workplace.

1. Introduction

Expenditure on machine condition monitoring and maintenance constitutes a significant budget item for many companies, especially in mining, metallurgical and processing industries. However, these issues are not well-represented in engineering curricula at tertiary institutions. At best, university engineering design units focus on design procedures and machine component design. Although project-based teaching [1, 2] is widely used to develop students in these areas, in many cases the projects are limited by their educational nature and do not necessarily reflect the latest developments in industry. This is where projects with a hands-on focus, closely tied to local industry demands and latest technology are seen as beneficial. In response to the burgeoning demand for tribology- and maintenance-related engineering skills by local industry, the Faculty of Built Environment and Engineering (BEE) at Queensland University of Technology (QUT) has placed particular emphasis on these aspects throughout the design component of the engineering degree, and introduced a new specialization (second major) called Heavy Mechanical Engineering.

Teaching of the elements of machine condition monitoring, tribology and maintenance at QUT is organised as follows. In the first engineering design unit − ENB215: Fundamentals of Mechanical Design − students study design procedures, and participate in a small-group "design and build" competition. This unit is taken by students enrolled in mechanical, biomedical and infomechatronic engineering first majors. In the third year of the mechanical engineering major, students take the second design unit − ENB316: Design of Machine Elements − and the third design unit − ENB317: Design and Maintenance of Machinery. Depending on the specialization chosen, students may also take the ENB434 unit: Tribology. Detailed content of these units as well as teaching approaches are discussed in the following sections.

2. Delivery of tribology and maintenance-related subjects

In the second design unit − ENB316: Design of Machine Elements − students study various machine elements, solid modeling and fundamentals of lubrication, while also undertaking a gearbox design project. The contact hours per week are as follows: two lecture hours, two hours of solid modeling, and two hours of tutorials/lab experiments. The gearbox design project is carried out in pairs of students. Each member of the pair is given the same gearbox specification, but different operating conditions, i.e. clean arctic conditions with subzero temperatures or, alternatively, a coal mine in tropical conditions, thus emphasizing a real-life practical focus in gearbox design. To further add realism teams use “Genius™” software from Bonfiglioli Riduttori (Italy) for the gearbox concept development, as shown in Figure 1. This interactive software guides students from initial type of gearbox, to the identification and consideration of up to five different candidates which students explore one-by-one. The students then justify what gearbox concept is most suitable for their operating conditions (dusty coal mine in tropical area or arctic conditions) and the rest of the project is then carried out individually, which includes kinematic calculations, selection of gear modules and teeth number, stress calculations for gears and shafts, bearing selection, housing design, development of a solid model of the gearbox and preliminary selection of lubrication system. This approach enables students to practice both in a team-based environment and individually. The authors have observed that collaboration shortens the learning curve and enables students to collaborate in the detailed evaluation of available design concepts.

With this approach, students are not just exposed to the theory of gearbox operation but also to the more general problem of solution, evaluation and selection using the experience and techniques provided by an industry-leading knowledge. This approach accelerates the development of graduates’ problem solving ability and prepares them for rapid integration in the workplace. For example, there have been numerous instances where students undertaking work experience were asked by their supervisor to recommend a mechanical drive for a real machine. These students, thanks to their experience using Genius software, in a short period of time were able to develop several recommendations of types and models of gearboxes to the great satisfaction of their industry supervisors. In addition to undertaking gearbox configuration selection, lifetime and strength design calculations, students must also make a detailed design of their gearbox using solid modeling software, in this case, SolidWorks™. Solid modeling classes are conducted by a contract tutor who is also a practicing design engineer. This approach brings together different design tools to solving a real-life project with both creative freedom and technical rigour.

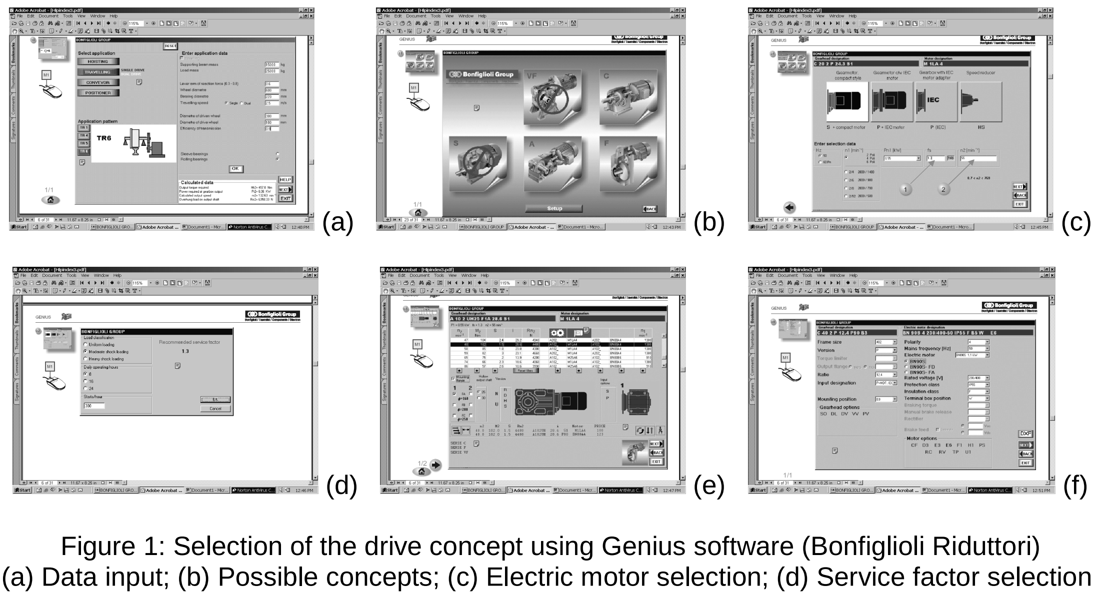
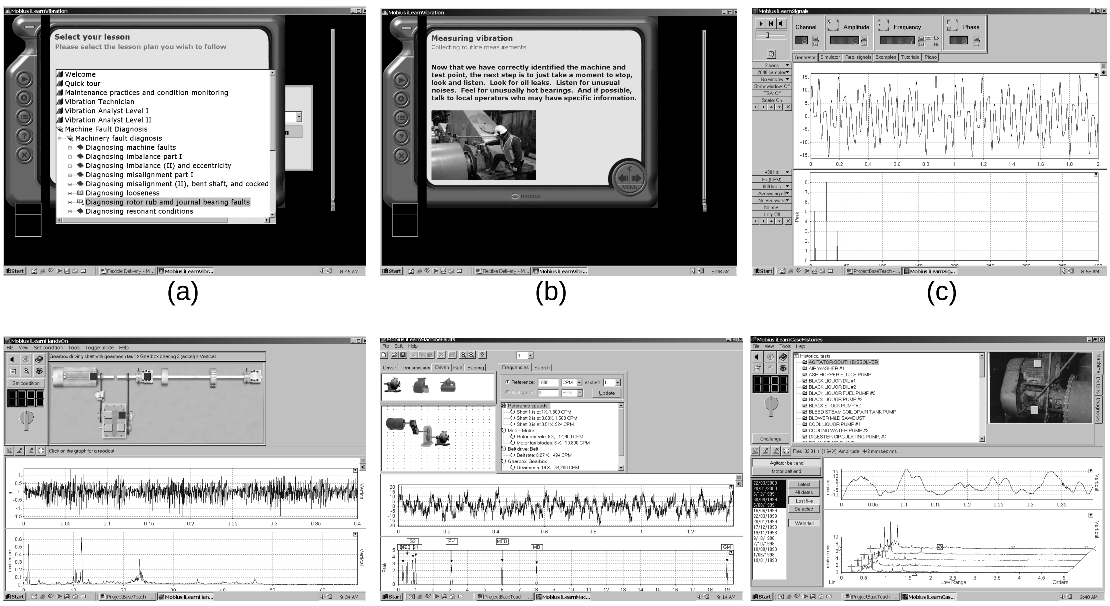


Figure 1: Selection of the drive concept using Genius software (Bonfiglioli Riduttori)
(a) Data input; (b) Possible concepts; (c) Electric motor selection; (d) Service factor selection; (e) Comparison of drive concepts; (f) Detailed drive specifications.

Alongside the mechanical component of the ENB316 design unit, students also study fundamentals of lubrication which they must apply to their gearbox project. The students must select the lubricant and lubrication method for the different components in their particular gearbox design. Detailed development of the lubrication system design and lubrication selection for the gearbox is performed as a separate project within the third design unit ENB317, as will be detailed further on.

To complement in-class and self study, students enrolled in ENB316 unit are taken for an industry visit to Terex Cranes Ltd. This company is a market leader in design and production of mobile articulated cranes. Students have the opportunity to see the latest developments in engine design, machine elements, different types of drives, computerized engine management and maintenance systems, as well as modern production systems using lean manufacturing. This visit aims to put the skills learned by the students in context of real engineering and locally relevant industry.

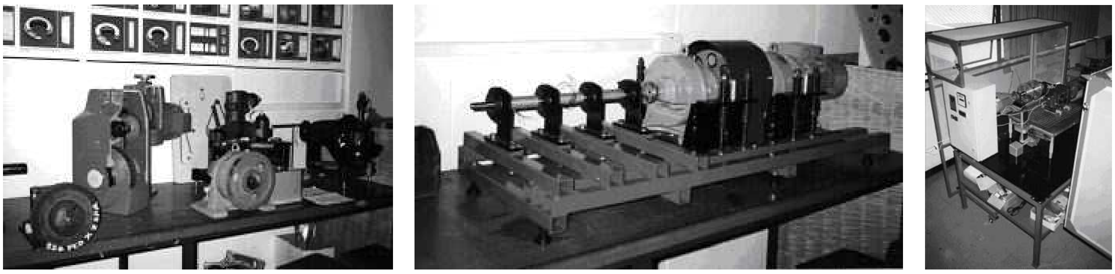
In the third design unit − ENB317: Design and Maintenance of Machinery − students study advanced machinery design, machine reliability and failure analysis, engineering optimization, machine condition monitoring, fundamentals of friction and wear and carry out a project on the development of lubrication and maintenance systems for the gearbox they designed in the pre-requisite unit ENB316. To facilitate learning of maintenance and machine condition monitoring with a hands-on focus, the I-Learn™ software from Mobius Ltd. (Australia) is used. It is an interactive package that includes the following modules and features: Animated lectures on different aspects of maintenance and machine condition monitoring; Signal processing with tutorials; Virtual machinery fault simulator; Simulation of different drive trains with analysis of characteristic vibrational signatures; Case histories of machinery failure, with machine photographs, vibrational signatures and fault description; I-Learn certification module that enables self-examination for different categories of machine condition monitoring qualification.



(a) (b) (c) (d) (e) (f)

Figure 2: I-Learn interactive software
(a) Main menu; (b) Module with animated lectures; (c) Signal processing module;
(d) Virtual machinery fault simulator; (e) I-Learn machine faults for transmission modeling;
(f) Case histories module of machinery failure with vibrational signatures.

QUT was the "launch" customer among the educational institutions for I-Learn software. This interactive package enables students during a short period of time (several weeks) to learn in a hands-on process the amount of information and practical skills that in industry environment requires many years. Laboratories and studios of the BEE Faculty are equipped with unique demo and test rigs that are also used for teaching. Some of the examples of this equipment are depicted in Figure 3. The machinery fault simulator shown on the right enables modeling of all typical mechanical faults such as misalignment, imbalance, rolling and sliding bearing problems, looseness, gearbox faults, flexible drives faults, etc. Students use this equipment both for study and for final year projects.



(a) (b) (c)

Figure 3: Demonstrational and test rigs in the Design Studio (from left-to-right):
(a) Sectioned gearboxes; (b) Cyclodrive test rig; (c) Machinery Fault Simulator.

To further enhance practical focus, team teaching is used engaging academics and technicians with specialist background as well as contract tutors with industry experience. For example, the team includes academics with expertise and experience in engineering design, computer modelling of transition processes in drive trains, machinery failure analysis, agricultural machinery, heavy machinery, machine condition monitoring, tribology; technicians with expertise in machinery, hydraulics, control systems, motor racing; contract tutors with expertise and practical experience in machinery design and solid modelling. Some academics hold many patents on different new types of equipment. With the team teaching different topics of the unit are delivered by academics with expertise in that area. This approach ensures the highest possible quality of teaching.

Students desiring to broaden their understanding of friction, wear and lubrication can take the unit ENB434: Tribology which is a core component of the Heavy Mechanical Engineering specialization (second major) and also can be taken as an elective unit by students enrolled in other specialisations. The teaching of tribology is sanctioned by QUT because of the recognition of the significance of lubrication and friction-related phenomena in machinery design and operation. It is a truly diverse and multi-disciplinary subject that is not done justice as a footnote to a mechanics unit. The unit is designed to educate students in all aspects of friction, lubrication and wear that they are likely to encounter as professional engineers, with particular emphasis on industries of economic significance to Australia, such as mining, materials handling and processing, and transportation. Emphasis is not just on professional practice but also on fundamentals in order to cater for those students interested in pursuing a research career. Unit content includes the following: the origin and fundamentals of friction; surface characterization; lubrication mechanisms; lubricant types and additive chemistry; lubricant selection, methods of application and maintenance intervals; design of plain sliding bearings and fluid film lubricated bearings; lubrication of gears, rolling element bearings using elastohydrodynamic lubrication principles and lifetime calculations; wear mechanisms, material selection and wear-rate calculation; practical case studies of industrial problems encountered by the lecturer.

The School of Engineering Systems has a wide range of tribology-related equipment, which students are encouraged to use. Much of this equipment has been designed and built by students undertaking tribology projects either in groups or individually. Examples of these rigs include: journal bearing rig, seal testing rig, piston-ring/cylinder-liner lubrication test rig, wet clutch test rig, elastohydrodynamic lubrication rig (see Fig. 4 and 5). Wear test rigs such as 4-ball test, Timken and Falex test rigs have been used for teaching and research projects. For example, the Timken test has been used to test lubricants by QUT Motorsport (in this project students design and build a race car for Formula SAE competition) for use in tripod couplings. The School of Engineering Systems also possesses internal combustion engine test rigs with dynamometers that are used both for teaching of a range of units related to design, sustainability, fluid and thermodynamics, as well as for research.

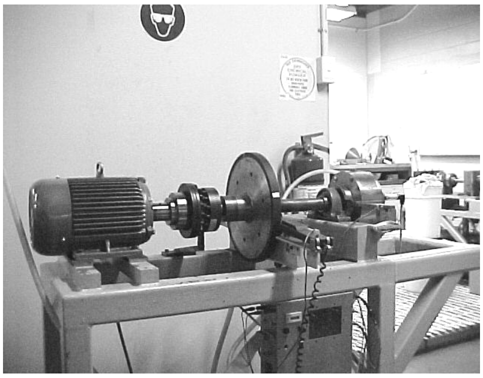


Figure 4: Wet clutch test rig

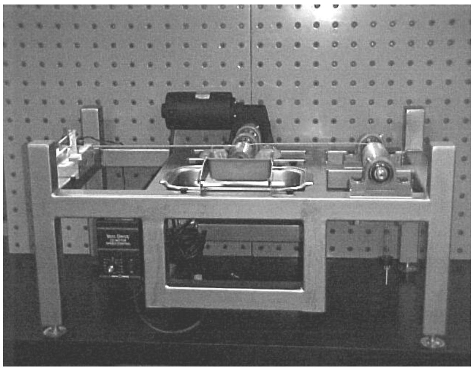


Figure 5: Lubrication test rig (Wire on drum test rig)

To complement teaching facilities available in laboratories and computer classes, course notes and laboratory manuals have been prepared [3, 4] that are available at QUT from unit-specific BlackBoard™ sites as well as books [5, 6], textbooks and design standards.

It is important to mention that the Cooperative Research Centre for Integrated Engineering Asset Management involving several universities has headquarters based at QUT. This gives both undergraduate and postgraduate students an opportunity to carry out real-life final year projects related to design, tribology and maintenance.

3. Evaluation of teaching approaches

In order to evaluate the efficacy of student learning in tribology and maintenance-related subjects, the following research approaches have been used [7]: experiment, case study and survey. In addition to statistical analysis of customised surveys, Learning Experience Questionnaires (LEX) were also used, enabling students to provide feedback online on the subjects that are the subject of this study.

In teaching and social research a number of research approaches can be used. In this research the authors focus on experiment, survey, artifacts analysis and case studies as research approaches [7]. The experiment in validating new approaches to teaching tribology and maintenance-related subjects is a part of a larger experiment conducted at QUT on validating new approaches to teaching design-related units. In conducting educational experiments researchers focus on contemporary issues and pursue answers to "how" and "why" question types [7]. For example, "How best to teach engineering graphics?" As a research approach, experiments enable control over behavioral events. The survey pursues answers to questions, such as "who, what, where, how many and how much?" Both case studies and surveys focus on contemporary issues (e.g. best practices) but do not allow control over behavioral events. Essential components of any case study are [7] "study questions", i.e. study propositions (what is the subject of exploration?); Units of analysis (students enrolled in particular courses); Linking data to propositions (pattern matching); Approaches for interpreting studies' findings (e.g. statistical methods).

Different methods can be used to validate results of a case study, for example, surveys, statistical analysis, interview, analysis of documents (students' assignments and project reports). An important question that researchers face is whether to make the case study anonymous or not. The authors chose to use anonymous case studies, as well as supporting surveys and interviews because people being interviewed or surveyed anonymously are more relaxed and cooperative.

3.1 Analysis of survey results

A survey questionnaire was distributed among the students that completed all three engineering design units (ENB215, ENB316, and ENB317). Many also completed the tribology unit, ENB434. Out of 32 responses, the statistical results of this survey are as follows. 80% of students *strongly agree* and 20% *agree* that, “Maintenance and condition monitoring are important components of mechanical engineering”. 60% students answered *very likely* and 40% *likely* to the question, “I will use the knowledge acquired on maintenance, lubrication and condition monitoring at some point in my engineering career”. 55% of students *agree* and *strongly agree* that they have been given enough knowledge and practical skills on tribology and maintenance. In the meantime 35% were *not sure*. 20% *strongly agree* and 50% *agree* that they can adequately select lubricants and materials after taking ENB316 unit, although 30% are *not sure*. 20% of students *strongly agree* and 30% *agree* that the visit to Terex cranes assists with their understanding of machinery and maintenance. Although 40% are *not sure* and 10% *do not think so*. This is easy to explain because approximately 50% students take this opportunity to visit the Terex cranes factory. Students that did not take this opportunity cannot judge on the usefulness of the industry visit. 60% of students *strongly agree* and *agree* that the I-Learn software is very helpful in gaining practical skills in condition monitoring. This percentage could have been much greater if all students took this opportunity and worked with all modules of the I-Learn software, including lecture module, virtual machinery fault simulator, case studies of machinery failure and the tutorial exercises module. 70% of students *strongly agree* and *agree* that Genius software from Bonfiglioli Riduttori is very helpful in visualizing gearbox concepts and shortens the learning curve. In the meantime 30% are *not sure*. 75% of students feel that after learning the basics of lubrication, friction and wear, they need to study more in depth and take specialized unit in tribology. However, 25% are *not sure*. This demonstrates that the majority of students appreciate the importance of maintenance and tribology subjects. 80% of students *strongly agree* and *agree* that the teaching resources provided and approaches used are adequate for acquiring hands-on and practical skills in design and maintenance. Although 20% are *not sure* or *disagree*.

Students were also asked open-ended questions. Typical answers to the question “What did you like most about engineering design units?” were as follows: “The hands-on design tasks, starting with concept development materials and lubricant selection”, “I enjoyed the practical aspects of the design units. The industry visits are always good”, “Practical – real life assignments”, “The lab practicals and using new software for engineering”, “The in-depth projects which helped to learn the engineering design process”. The question “How would you think we could further enhance the hands-on and practical focus in engineering design units”, attracted the following answers: “Devote more time to practical experience and increase the lubrication content if it is to be examined”, “More practicals”, “Visit to actual gearbox manufacturer”.

It is important to mention that the Faculty of Built Environment and Engineering recently introduced flexible laboratory arrangement moving from permanent, subject-specific laboratories, to general laboratories with minimum permanent equipment. Most test and demo rigs are stored at on-campus and off-campus warehouses and setup in class when necessary. Both academics and students are still getting used to the new arrangement and assessing its benefits and shortcomings. Students have not made any comments on this arrangement to date.

3.2 Analysis of Learning Experience survey results (LEX)

At the end of each semester at QUT, students are encouraged to provide their online responses to learning experience in different units. Using a five-point system, students provide their responses to questions and also comments on what they liked the most and what can be improved about a particular unit. For units related to maintenance and tribology students ranking of different aspects of teaching from year to year are in the range of 4.3 to 4.7, which reflects high level of student satisfaction with these units. Some students’ comments are as follows: “Lecturers bring a wealth of experience and expertise to the teaching of the unit”, “…the real life examples made this unit most interesting and useful”, “The best learning experience out of all units taken at the university”. Analysis of survey and LEX results show that students overwhelmingly appreciate the hands-on and practical focus of the subjects.

Among the comments on what can be improved students suggested to prepare animations and more hands-on exercises and experiments in laboratories. Students also suggested to organize visits to gearbox manufacturers. The suggestions are used for continuous improvement of both the content and teaching approaches. Once a year every academic at the Faculty of Built Environment and Engineering at QUT has a Performance Planning and Review meeting (PPR) with one of the senior managers (usually the Head of School, the deputy Head or a discipline team leader). During PPR meetings achievements for the year are summarized and performance targets are set for the year ahead. Part of the meeting objectives is the discussion of unit improvement measures based on feedback from students, colleagues and technicians, and preparation of the unit improvement flowchart for each unit where the particular academic is a unit coordinator.

4. Conclusions

1. In this paper, the important issue of teaching tribology and maintenance-related subjects is discussed.
2. New approaches to teaching have been presented with practical and hands-on focus. These approaches include:
   - Team teaching engaging academics with specialist background and experience in design, machine condition monitoring, machinery failure analysis and tribology, technicians and contract tutors with industry experience.
   - The use of interactive software packages such as I-learn training package for hands-on teaching of machine condition monitoring, and Genius software for gearbox selection.
   - Industry visits to companies such as Terex Cranes Pty. Ltd. where students have the opportunity to observe modern design solutions and production methods.
   - Real-life projects, such as gearbox design, whereby part of the project is carried out in a team of two students and the rest of the project individually, for different operating conditions (e.g. arctic and tropical).
   - Continuing projects when, for example a gearbox project is carried out in one design unit and a project on the development of lubricating, condition monitoring and maintenance system for that gearbox is carried out in a design unit that follows.
3. To evaluate students’ satisfaction with new teaching approaches, the following methods were used:
   - Special sets of questionnaires for students that completed all engineering design units and the specialist tribology unit. These questionnaires also included open-ended questions on what students like most in each unit, and what they think can be improved.
   - Online learning experience survey (LEX).
4. Questionnaires and surveys showed the following:
   - Students appreciate the importance of studying maintenance and tribology and believe they will use this knowledge in their engineering career.
   - Students overwhelmingly support the hands-on and practical focus in teaching.
   - Students understand the necessity to study in-depth tribology after studying engineering design units where they are given a basic introduction to lubrication, friction and wear.
   - Most students believe that they are given sufficient knowledge on friction, wear and lubrication after completion of three engineering design units and tribology unit, enabling them to adequately select lubrication strategies for different machinery.
5. The feedback obtained in this research validates the new approaches developed for teaching tribology and maintenance-related subjects

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