Teaching Engineering Design using Modular Methods with Virtual Tools

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CONTEXT

Design practice for the successful design of engineering systems expects design engineers to possess a vast subject knowledge of different engineering systems and acquire a set of design skills which are typical of a senior engineer with many years of design experience. Further, design tradition often requires the creation of a physical prototype to verify the design progress against the project specifications and to perform early product acceptance testing.

As a senior design engineer at the Centre for Medical Radiation Physics, University of Wollongong, the author was instrumental in improving the design process of complex systems by incorporating a modular design methodology to reduce the complexity of the design through partitioning into functional modules. Verification of the design was achieved through virtual mode testing of the design with virtual tools such as Altium, Multisim, Solidworks and Ansys Simplorer.

PURPOSE

The title of this research is “Teaching Engineering Design using Modular methods with virtual tools”. This work reports on the efficacy of teaching the art of modular design methods with virtual tools to mature-age engineering students undertaking postgraduate studies in SEE712 Embedded Systems at the School of Engineering, Deakin University.

APPROACH

Additional lecture and laboratory material were created for presentation to mature age postgraduate engineers studying SEE712 Embedded Systems. The presentation material included lecture slides with notes, and laboratory examples and a case study. Surveys of the students were taken prior to the start and after completion of the course seeking opinions students of the course expectations and whether the course delivered those outcomes. Examination results were collated and analysed to corroborate the survey results and to provide a measure of the effectiveness of the new design methodology to improve the students’ engineering design acumen.

RESULTS

The paper clearly shows the improvements in both the students’ opinions of their capabilities prior- and post-instruction together with questionnaire results.

CONCLUSIONS

Preliminary results show that the teaching of modular design methods greatly improves the capability of a student engineer to more easily handle the design of complex systems. It also instils a new found confidence in their belief in themselves as a design engineer.

KEYWORDS

Postgraduate teaching in engineering design, modular design, virtual tools, functional partitioning.

Introduction

For many decades now, employers have claimed that not only has there been a shortage of qualified engineers available to fill engineering design positions but many employment surveys, such as published shown in a report by Experis Engineering (2016), demonstrated that the problem was never a shortage of qualified engineers but a shortage of qualified engineers who possessed the necessary skills for the advertised positions. Moreover, the most commonly cited reason for unsuitability of applicants was not a lack educational qualifications or knowledge, but their lack of experience or a deficiency in their presented skill set.

A literature review by Markes (2006) revealed that over 20% of the productivity gap in Britain compared to France and Germany was attributable to the lack of British workers with the necessary skills. However, more work needs to be done to determine the teaching requirements for the missing skills. As these skills are continually changing, the teaching requirements will change accordingly: this, it is claimed, can only be achieved through cooperative, inclusive, transparent and centrally coordinated approaches to skills identification, assessment and development. For example, Engineers Australia (2012) made the following submission to the Australia Senate Education, Employment and Workplace Relations References Committee:

- That all Government agencies should work to retain internal engineering expertise in their workforce. This could be achieved through the creation of senior technical specialist roles — such as Engineering Associates — that would provide a technical career pathway (in tandem with traditional managerial/generalist career pathways) for those seeking to build specialist knowledge while continuing to enjoy career/hierarchical progression; and
- That Australian governments, through the Council of Australian Governments (COAG), ‘transition to a seamless economy’ reform process and support the introduction of a nationally consistent registration system for engineers in which profiles of graduate engineers can be retained, monitored and updated.

Engineering Associates

In the past, to overcome the deficiency in skills presented by a new inexperienced graduate employee, employers would pair the new employee with a highly skilled semi-professional, such as an Engineering Associate (EA), as a mentor. The EA was educated to at least an advanced certificate or diploma level from a TAFE or polytechnic, and had acquired many years of engineering experience at the trade and advanced technician levels, particularly with this employer: this included in-house documentation which followed special company rules or formats, ordering procedures, and the correct personnel to see when seeking workplace approvals. EAs had developed a high level skill set but lacked a formal graduate qualification which would permit them to enrol as a corporate member at an Engineering Institution.

EAs generally had a wealth of practical experience in installing, testing and monitoring equipment and systems, both in the operation and maintenance of advanced plant and in selecting and supervising tradespeople in these activities. EAs are often employed as experts when selecting equipment and components to meet given specifications, and in assembling these to form systems which are customised to particular projects. Employers expect EAs to have an understanding and detailed knowledge of Standards and Codes of Practice, and to be expert in their interpretation and application to a wide variety of situations in the workplace.

Many EAs developed very extensive experiences in practical installations and are often more knowledgeable than a professional engineer or technologist and can contribute very greatly to equipment safety, cost or effectiveness in operation. In other instances, EAs developed high levels of expertise in all aspects of design and development processes. These might include, for example, the use of advanced software to perform detailed design of structures, mechanical components and systems, manufacturing or process plant, electrical and electronic equipment, information and communications systems, and so on. Other examples might be in the construction of experimental or prototype equipment. Again, experienced operators in these areas often develop detailed practical knowledge and experience complementing the broader or more theoretical knowledge of others. EAs generally have a good grounding in engineering science and the principles underlying their field of expertise together with an ability to communicate well with graduate engineers who act as their superior and to the lower level trade people who may doing all the grunt work. In some instances, EAs may lead or manage lower level teams appropriate to these activities or move into more senior management roles in engineering which could include managing of professional engineers.

Skills Training of Graduates

In a recent publication by Littlefair et al. (2012), the development of the Centre for Advanced Design in Engineering Training (CADET) at the School of Engineering, Deakin University will go a long way to address the critical engineering skills shortage. In their paper it was stated that "CADET is proposed to be a teaching and learning facility providing a project focused modern engineering approach to students at regional schools and TAFE as well as Deakin's degree programs. CADET will emphasize engineering design and development through virtual and physical modelling, simulation and prototyping – skills at the heart of the 21st century engineering challenges, and will serve as an attractor to engineering and related professions".

Palmer et al. (2008) suggested an outcomes-based accreditation system could be centred on the demonstrated attainment of appropriate graduate attributes by an individual student, attributes which might be delivered or gained by a range of means including distance education. Unfortunately, this approach simply takes a snapshot in time of the graduate's skills attributes which will soon become dated with the effluxion of time. What is really required is a skills record, or a certified history of skills and accomplishments which would provide a better profile of the engineer's attributes.

One method suggested by Hassan et al. (2013) to help reduce the deficiency in the skill set of undergraduate engineers was the introduction of Final Year Engineering Projects (FYEPs). This work suggested that by using the FYEP method one can improve and demonstrate a student's collective learning experiences gained during their undergraduate education and training phases. Like Palmer et al. (2008), method simply provides a snapshot in time of the graduate engineer's skills attributes.

Whatever the skills to be acquired by a student during undergraduate training, industry surveys conducted over many decades continue to show that the acquired skill sets may still not be sufficient. This suggests that there is a disconnect between the skill sets required by industry and the skill sets offered by the teaching institutions.

Teaching of Engineering Design Skills

Engineering design practice often requires the creation of a physical prototype to verify the design progress against a set of project specifications (Dieter et al. (2009)). The creation of a physical prototype often imposes a major cost barrier to small design groups, which have little supporting funds, or to engineering students enrolled in distance education with no ready access to a workshop

System designers and integrators need to deliver ever more complex systems, and fundamentally change how they design, build and commission systems. Fortunately, recent advances in design software can help with that, whilst also delivering longer term operational and maintenance benefits. A common strategy for reducing the design complexity of any convoluted system is to partition it into sub-units, or modules, as has been clearly described in Dieter et al. (2009) where the decomposition of a complex system into smaller functional modules that will faithfully represent the original system when they are recombined. Barrington et al. (1993) argued that one purpose in partitioning a system was to produce a set of loosely-coupled modules, each of which is highly cohesive to the other partitioned modules and where each cohesive module represented a single part of the system functionality. As a result of system partitioning, inexperienced designers would find the design task significantly reduced.

Modular Design

One design methodology that fully utilizes the partitioning process to reduce the complexity of a system is Modular Design. Bryan et al. (1990) presented a new approach in the design of radiological instrumentation by using the modular design methodology in its development. Their work demonstrated that the use of modular design methodology produced significant improvements over conventional instrument design methods in terms of product capabilities, maintainability, and overall system cost. The benefits of modular design do not automatically spring from simply partitioning a complex system into modules. The way in which a system is partitioned can make an enormous difference to how easily the modules are designed, constructed and reconnected. Each module should encapsulate specific design information from the product specification and should not be replicated in other modules. This information-hiding feature reduces the cost of subsequent design changes: for example, a module may encapsulate related functions that can benefit from a common implementation that is used in many parts of a system, or a functionality that is likely to change during later design or deployment, or aspects of a problem that are particularly complex, or code that is expected to be reused in other programs.

Module reusability can be a major cost saving feature if modular design is used. Not only does it reduce time spent in design, implementation and testing of the module, modular design also allows development costs to be amortised over many projects. Numerous studies have shown that reusing the product design is by far the most effective technique for reducing product development costs: El Saddik et al. (2001) developed dynamic multimedia objects using dynamic metadata which they referred to as smart learning objects whilst Aoyama et al. (2003) demonstrated the production of a camera how reusability was enhanced by using product modularisation; they also point to the early introduction of modular design in the automobile industry where an unnamed vehicle manufacturer obtained a substantial cost saving each year by using a common module within a vehicle family; Gershenson et al. (1997) argued modular design should also include a factor for on-going maintenance in an expanded definition of modularity, they claimed that this would produce a more robust product by improving its the on-going serviceability and maintenance; Alagar et al. (1992) agreed with this premise and suggested that as their object-oriented paradigm provided a unifying model to integrate the phases of software development, it would be better able to cope with evolutionary changes more easily and encourage reusability.

Virtual Design Space

A system design made in the modular-design mode, or virtual design space, can increase the design productivity and minimise risk (Kozak et al. (1990), Khalgui et al. (2011), Huss (2007) and Altera Corporation (2007)). The ability to validate, test and optimise the system independent of physical hardware can reduce project costs and minimise commissioning and start up time but this presents a new challenge for automation system designers and integrators. System designers are now expected to deliver flexible and information-enabled automation systems ready for smart manufacturing, while also contending with pressures to increase profitability and innovation, reduce time-to-market, optimise asset performance and meet all regulatory standards.

Research Method

To test the hypothesis that modular design improved design skills in new graduates, SEE712 - Embedded Systems, a current unit for teaching engineering design for embedded systems to postgraduate students in the School of Engineering, was selected as a suitable course candidate. SEE712 - Embedded Systems introduces students to the principles and practices of embedded systems design using advanced programmable techniques and CAD tools. Students will on average spend 150 hours over the trimester undertaking the teaching, learning and assessment activities including face-to-face contact of 4 hours per week as a 2-hour lecture and 2-hour tutorial with problem-based exercises.

At the successful conclusion of the course, students will be expected to have acquired detailed understandings in the following:

- the hardware and software aspects of embedded design practices which use programmable devices and hardware description languages;
- program development for programmable devices using software tools available for embedded design; and
- design procedures for an embedded system and its implementation on an embedded platform through group learning and project work.

To measure the efficacy of this approach in teaching engineering design, an on-line questionnaire was presented to each student after the completion of the course — see Brace (2004). The purpose of soliciting answers to these questions in this way is to gain an understanding of the reasons why students decided to study this course in particular, what were their expectations, were their expectations satisfied, and were there any comments regarding the content of the syllabus or conduct of the course. After the surveys were completed, the data were collected and the survey answers were analysed.

Results

Course Experiences

The modified lecture material describing the modular design methodology was presented in Trimester 1, 2016. Students were then trained in the modular design process and how to partition a system into functional modules and presented with a questionnaire soliciting opinions of their experiences with the modified course and their ability to satisfactorily handle the design of a complex system.

The Questionnaire selections and percentages for each answer are shown in Figure 1 Questionnaire Selections Q1 to Q8 and the following question list. There were 20 submitted surveys. Each segment of the histogram bar compares the percentage results of each selection presented; Selection values were Sel1 implied very high agreement, Sel2 was a high agreement, Sel3 was a medium agreement, Sel4 represented a low agreement, Sel5 represented no agreement.

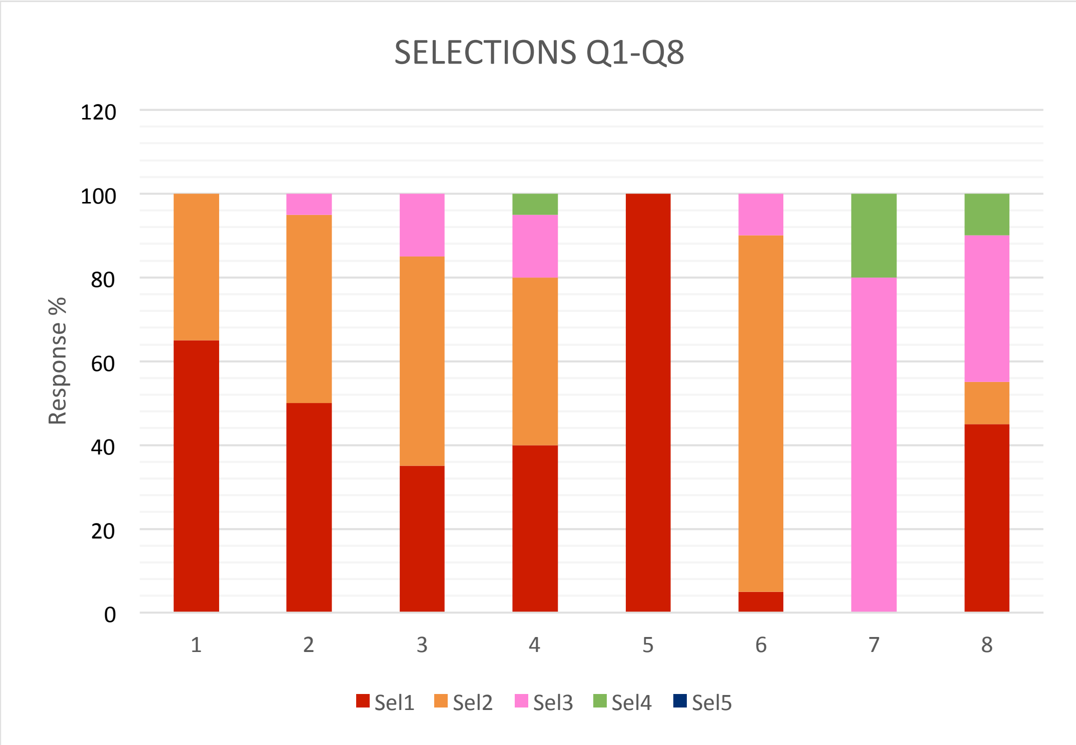

Figure 1 Questionnaire Selections Q1 to Q8

Question and Answer Breakdown

Q1. How has studying SEE712 improved your ability to determine the functional modules of an engineering system? — 65% chose a “very high agreement”,35% selected a “high agreement”. Student responses appeared to respond favourably to the new direction of the course.

Q2. How has participation in SEE712 Embedded Design course improved your ability to design or model an engineering system? — 50% of the replies were “extremely high agreement” while 45% were “high agreement”. These responses were in respect to how students’ felt their participation in the modified SEE712 Embedded Design course improved their ability to design or model an engineering system.

Q3. How much has the completion of SEE712 Embedded Systems improved your understanding of functional design? — The results show over 80% of students felt their studies contributed a “high” to “very high” improvement in their understandings of functional design, a key feature in modular design.

Q4. How much has the completion of studying SEE712 Embedded Systems improved your understanding of Complex Systems? — These results confirm that over 80% of students agreed to the proposition that the modified course improved their understanding of complex systems.

Q5. Has SEE712 Embedded Systems provided you with a clear understanding of the Modular Design process with respect to the reduction in the complexity of a system design? — 100% of students agree at a “very high” level with this proposition.

Q6. How much has studying SEE712 Embedded Systems shown you how to reduce the complexity of a system design by using the Modular Design method? — Only 5% of students agreed at a “very high” level with this proposition whilst 80% agreed at a “high” level.

Q7. Do you feel the course details of SEE712 Embedded Systems can be improved, reduced or is about right? — 80% of students agreed at a “medium” level whilst 20 were at a “low” level of agreement. One suggested: “It would have been better if we have some advanced systems and since we are working in a team it would be great if we could do some real time projects”, another suggested: “VHDL should be taught in more detail, just not stick to the basic one or that may help in the project. The software used should also be taught in detailed [sic]”.

Q8. Select one ONLY of the following statements that best defines the Modular Design process as described in the SEE712 Embedded Systems course. — Responses were evenly divided in answer to this question: 45% of students gained the best understanding of the purpose for modular design being used in this course.

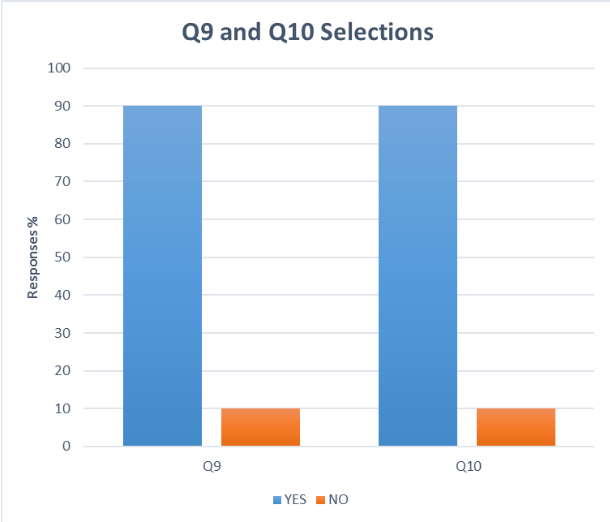

Figure 2 Questionnaire Selections Q9 and Q10

Q9. Have your expected outcomes in improving your engineering design skills been achieved through studies in SEE712 Embedded Systems? — Students were asked to compare their expectations for this course against their actual outcomes to determine if they achieved any improvement with their engineering design skills through studies in SEE712 Embedded Systems, 90% of students agreed with this proposition.

Q10. Do you wish to continue your postgraduate studies in engineering design? — 90% of the students agreed that they wished to continue their postgraduate studies in engineering design. One suggested work in:: “Circuit designing and Networking based projects”; while another suggested: “a desire to work on few advanced robotic projects in the coming future”.

Conclusion

The results show a clear set of positive student satisfaction for the engineering design course using modular design methodology they had recently completed. Of note are the comments in the responses to Q7 to improve the course syllabus, namely, introduce team based designs at advanced systems levels and a more comprehensive training in VHDL for FPGA control in the systems design process. The limitation to this research has been the restriction on access to Students’ records to provide anonymity imposed by Ethics rules. The results show that the teaching of modular design methods greatly improves the capability of a student engineer to more easily handle the design of complex systems. It also instils a new found confidence in their belief in themselves as a design engineer.

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