

Connecting Teaching and Research Through Problem Based Learning in Thermal and Automotive Engineering

Yasir M. Al-Abdeli

School of Engineering, University of Tasmania, Hobart, Australia
Yasir.Alabdeli@utas.edu.au

Frank Bullen

School of Engineering, University of Tasmania, Hobart, Australia
Frank.Bullen@utas.edu.au

Abstract: *The effectiveness of problem based teaching in promoting experiential learning is well established. Literature highlights a number of innovative teaching techniques and case studies that have been applied to enrich curricula in thermal, automotive and product design. This paper reports on a new approach that has been adopted to invigorate undergraduate coursework in mechanical engineering design. The methods described are applied to small groups of students working in a case study, design-based, learning environment to promote understanding of thermal and automotive engineering principles. The overall challenge is to design a cooling system for an internal combustion engine. Lecture notes convey the fundamental knowledge required to accomplish the design while augmenting and linking that knowledge with the outcomes of current research in the field. This linking facet of the teaching process allows the nexus between teaching and research to be explored by the students within the PBL platform.*

Keywords: *Teaching-Research Nexus, PBL, Design.*

Introduction

Many studies have been undertaken on the teaching-research nexus. Whilst some investigators have tackled the implications, or even existence, of a teaching-research nexus in academia, others have addressed this relationship from a learner's perspective. Strong perceptions have been voiced amongst (senior) academics for the existence of a multi-faceted relationship between university teaching and research (Neumann, 1992). The nexus appears to manifest itself differently at various levels of undergraduate education (Neumann, 1992). At the same time, other evidence either casts doubt on the existence of any such (positive) nexus, in academia (Ramsden & Moses, 1992), or indicates a very weak (positive) correlation between teaching and research quality (Hattie & Marsh, 1996). To reach such contrasting views is however not surprising given the lack of commonly accepted or applicable quality measures which are able to assess the strength and nature of either component of the nexus, *teaching* and *research* (Brew & Boud, 1995). It is the authors' view that an appropriate methodology to enhance the teaching-research nexus is the incorporation of "research" level material in teaching utilising a problem based learning approach.

Looking at the nexus from a student's perspective and by analyzing the nature of both teaching and research, it has been shown that "learning" appears to be a common denominator between both these academic activities (Brew & Boud, 1995). Studies have also shown that

students find fusing research outcomes into a teaching context not only demonstrates that knowledge is continuously evolving, but can also provide an environment for better student-teacher interaction (Neumann, 1994). Other studies have simultaneously emphasized that the correlation between research and teaching can be fostered (in students) by providing assignments that stimulate deeper or inquisitive modes of learning (Hattie & Marsh, 1996; Clark, 1997). Generic attributes expected of (modern day) practicing engineers can also be reinforced in students through a (positive) relationship between research and their education (Casar, 2000). It is therefore not surprising that some studies have questioned whether enough is being done to impart more research-oriented approaches in student learning via team and problem-based methods (Brew & Boud, 1995).

On another front, the merits of both problem- and team-based (Al-Abdeli & Bullen, 2005), or "formal cooperative learning"(Smith et al., 2005) are well known in engineering education. An important issue here is that students seem to favour project work that allows knowledge gained to be placed in real life applications (Stouffer et al., 2004). However, because assigned work drawn from the realms of engineering applications generally transcends specific (conventional) disciplines, introducing such work in the classroom is also challenging from the teacher implementation perspective. One important factor when selecting such problem based work is the degree of (initial) familiarization that students have with the systems being considered (Farrell et al., 2002). Here, the literature cites a number of good examples where problem based learning or design work has been applied, wholly or partially, to thermal engineering (Roy et al., 2002), chemical product design (Farrell et al., 2002) and automotive engineering (Deb, 2002). Students going through a "design metaprocess" also gain and develop the more complex problem solving abilities and personal attributes expected by their employers (Ramers, 2002). Problem Based Learning (PBL) can lead students to an appreciation of advanced "research" level knowledge as they develop such abilities.

With the above in mind, a PBL approach was applied to a design oriented undergraduate engineering unit taught at the University of Tasmania. Unit KNE355, Design for Manufacture, typically includes three case studies being taught by different staff over a single semester period (thirteen weeks). The inclusion of multiple staff in the teaching process means that a more diverse range of design cases may be considered, particularly as people with different research interests are involved. The paper highlights the details of one case study focussed on a thermal and automotive engineering application (over five weeks of student work). After describing the case study and the requirements of the overall design submission, the paper goes on to describe how the teaching-research nexus was fostered in the context of the overall learning experience by using PBL to explore research findings. Some of the steps implemented to actively promote more effective team-based work are also described.

The Case Study

The main strength of the teaching approaches applied is to demonstrate how PBL can address a number of different learning issues in undergraduate curricula while simultaneously exposing students to relevant research. Figure 1 reflects this view and also shows that central to implementing the learning experiences described is the design oriented nature of the course. In this regards, the ultimate aim of the assigned work was to design a radiator assembly for an Internal Combustion (IC) engine. Figure 2 depicts a general layout of the anticipated radiator assembly and one typical application scenario. Achieving the overall design project necessitated that the following five components be satisfied by the student teams:

- ❑ Thermal sizing of the radiator core (based on a compact heat exchanger)
- ❑ Physical design and engineering drawings of the complete radiator assembly (around the core)
- ❑ Consideration of safety issues for the designed product
- ❑ Awareness of current research and/or technology which can potentially impact on radiator fabrication, performance, design or materials.
- ❑ Preparing a final written design submission covering all the above
- ❑ Providing a short presentation of the above

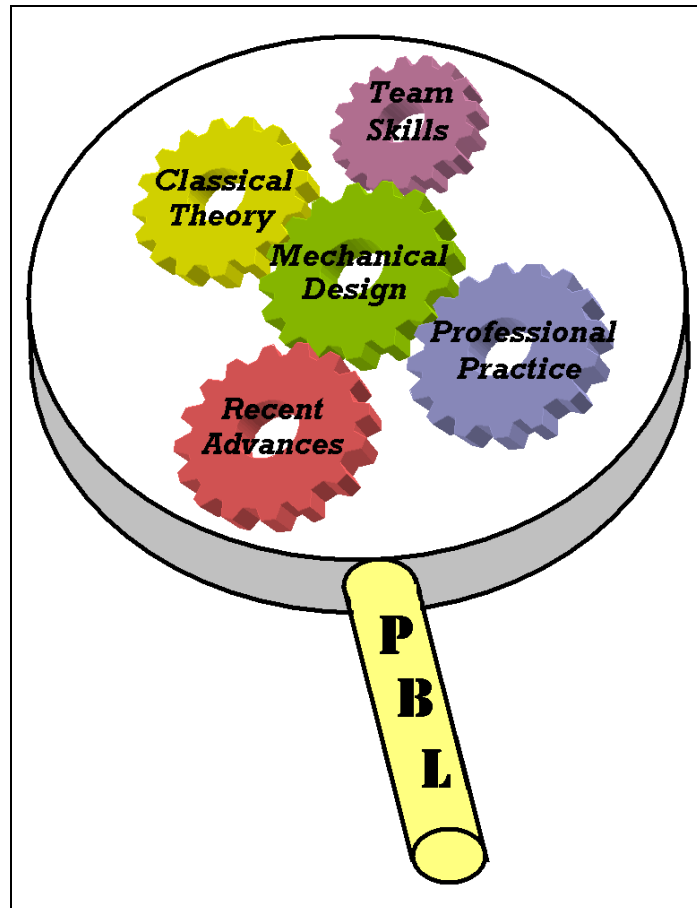


Fig 1: PBL allows a number of learning outcomes and experiences to be simultaneously explored.

The Teaching

Before assigning the work, five hours of teaching were dedicated to delivering relevant (core) knowledge to students. Table 1 lists the range of topics covered, which essentially encompass the traditional (coursework) subjects of automotive engineering and heat transfer. This coverage was necessary because although all students possessed some basic understanding of thermodynamics and other subjects like materials/manufacture, some had not yet progressed to or completed heat transfer. Students also do not undertake a dedicated automotive engineering unit of study prior to attending KNE355. These aspects in addition to the fact that those enrolled had completed different years of the engineering degree (second and third) presented an additional challenge in the teaching process. For the automotive engineering part, lectures discussed the range of high temperatures anticipated in IC engines and the different forms of energy exchange (input: fuel; output: useful shaft work, engine cooling,

exhaust, etc.). The two basic forms of engine cooling in modern engines (air-cooling, water-cooling) were then tackled along with typical applications. The lectures then focussed on water-cooled IC engines and radiator variants according to (coolant liquid) flow direction. The different components that form the radiator assembly were then individually covered. The second topic treated by the lectures was heat transfer. The principles of steady state heat transfer were first covered before discussing heat exchanger analysis. The application of the Log Mean Temperature Difference LMTD method to parallel- and counter-flow heat exchangers was then focussed on. This allowed cross-flow heat exchanger analysis to be then covered along with some of the variants in tube-fin exchanger designs. A number of excellent monographs were utilized across the automotive engineering (Crouse, 1970; Crouse & Anglin, 1981, Knowles, 1985; SAE HS-40, 1991) and heat transfer lectures (Incropera & De Witt, 1996; Kays & London, 1984). Figure 3 shows a general schematic of the (anticipated) overall steps which students had to undertake as they progressed towards achieving the radiator design.

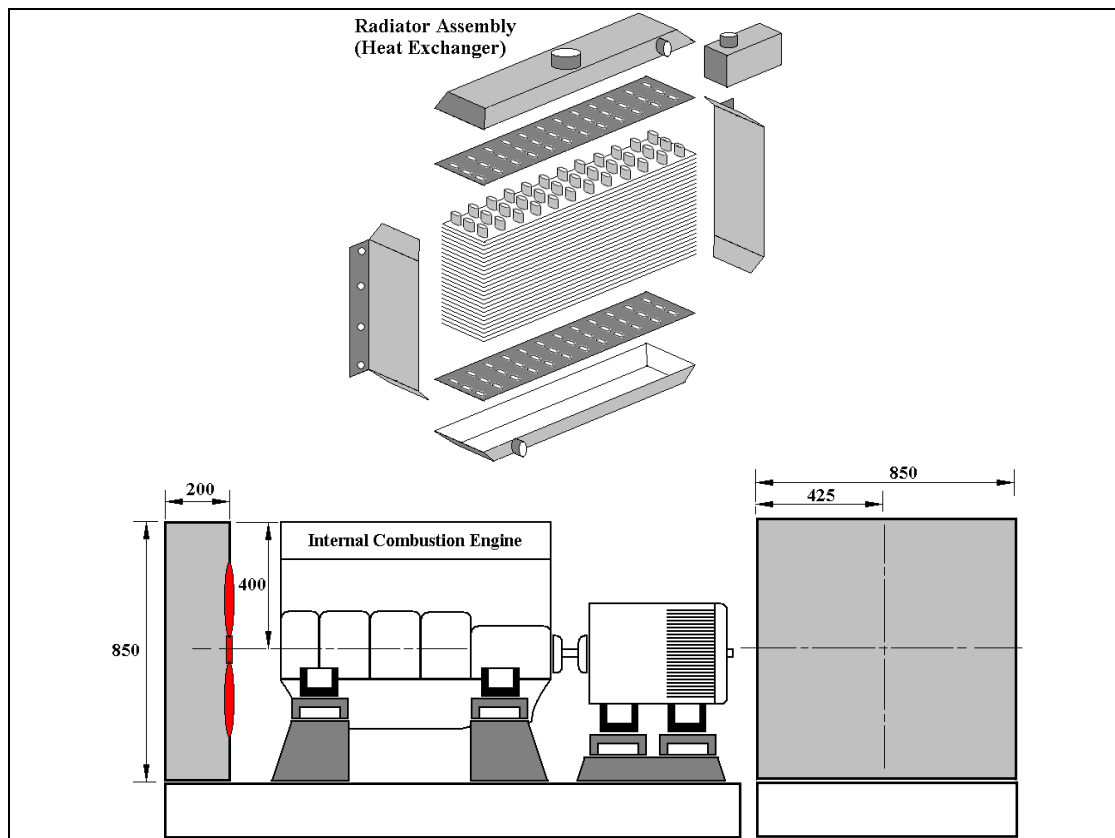


Fig 2: The radiator assembly (left) and intended application scenario (centre, right), a platform mounted internal combustion engine/generator set.

Fusing Research Findings into the Learning Experience

In addition to conveying core knowledge, lecture notes also made reference to findings from a number of relevant and "recent" journal papers (Pang & Brace, 2004; Yuksel & Ceviz, 2003; Watkins & Johnson, 2004; Sathyanarayanan & Ramprabhu, 2005; Chen et al., 2001; Taler, 2004; Selim & Helali, 2001). Other more practically oriented content was also selected from a number of magazine articles that tackled engine cooling systems and similar matters (Deierlin & Gelinas, 1988; Markovich, 1992; Stewart, 1999, 1998). All in all, these papers and articles supplemented the lecture notes by exploring a number of relevant issues, including:

- Engine performance: the role of cooling on the overall energy balance and performance of engines as well as the role which engine power (output) can have on heat transfer through cylinder walls.
- Vehicle flow dynamics: the effects of vehicle frontage design on (air) flow characteristics at the radiator face.
- Operational fluids: the effect of coolant additives and temperatures as well as (fan) air flow rate on heat transfer.
- Cooling system operation and design: considerations in the use of plastic end tanks and how fan positioning is related to the distribution of debris which accumulates in the radiator core (due to air flow).

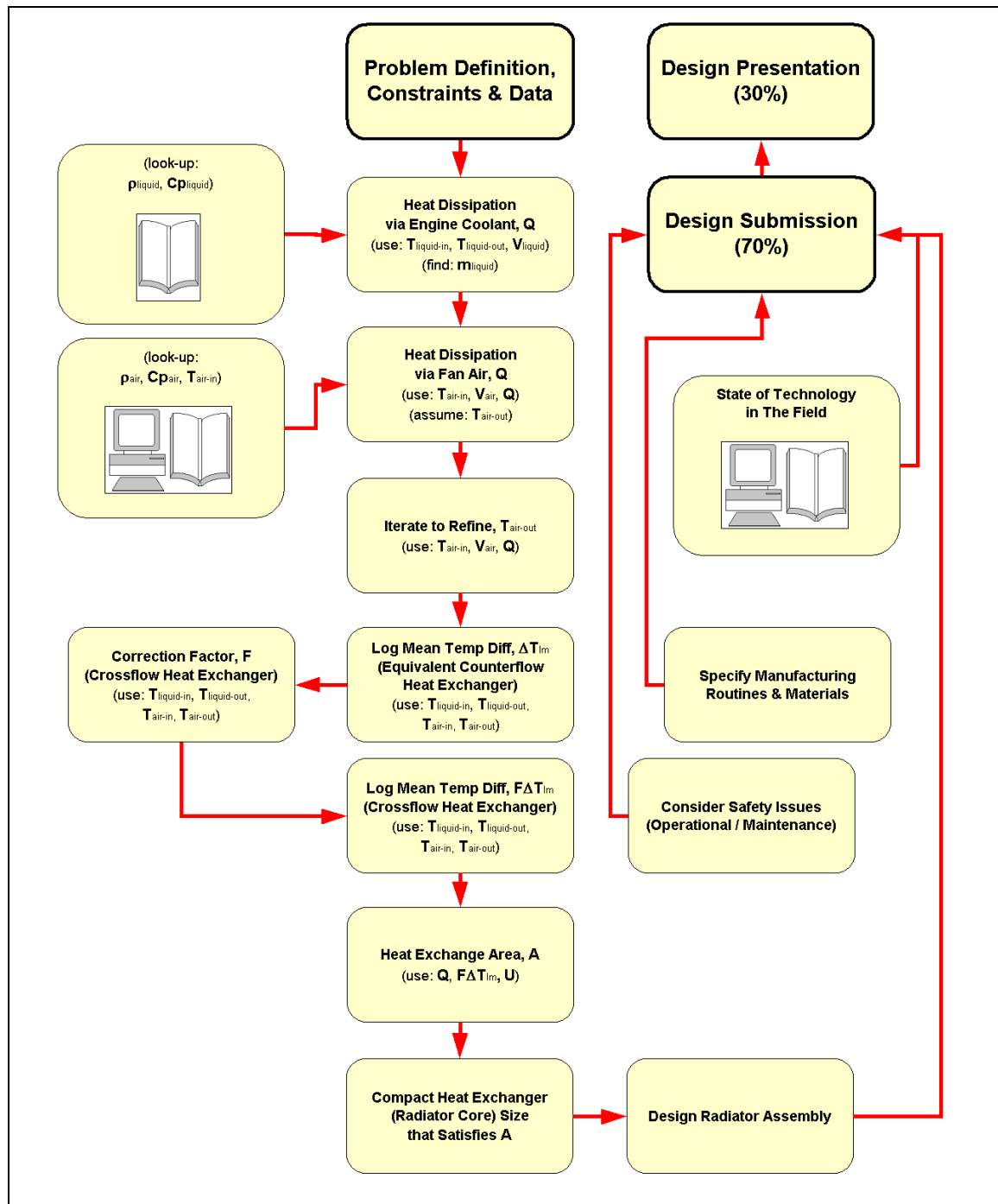


Fig 3: The basic steps and tasks required for arriving at the final design submission.

| | |
|---|---|
| Internal Combustion Engine Cooling Systems | Why is Engine Cooling Needed Energy Balance: Inputs & Outputs How is Engine Cooling Achieved Significance of Engine Temperature Forms of Engine Cooling <i>Air Cooled Engines</i> <i>Water Cooled Engines</i> Radiator Operation: The Cooling Cycle Radiator Flow Direction <i>Downflow Radiators</i> <i>Crossflow Radiators</i> Radiator Design: Cores Radiator Operation <i>Fan & Shroud</i> <i>Front Grill</i> <i>Pressure Cap</i> <i>Expansion Tank</i> <i>Coolant Liquid</i> |
| Elements of Heat Transfer | The Plane Wall Thermal Resistance Composite (Wall) Thermal Resistance The Fouling Factor Fins Heat Exchanger Analysis <i>Parallel Flow Heat Exchangers</i> <i>Counterflow Heat Exchangers</i> <i>Crossflow Heat Exchangers</i> Compact Heat Exchangers Some Research & Outcomes |
| Table 1 Topics covered by the lectures. | |

Actively Energizing Team Based Work

A recent study has emphasized a number of ways in which team based student work, in its "formal cooperative form", can be actively enhanced in student group work (Smith, 2005). Three relevant factors (Smith, 2005) are quoted below along with some explanation as to how they were actively promoted during the present teaching process:

- "Individual accountability / personal responsibility": The issue here is to reinforce and develop the responsibilities of individuals as they work within their group and to realize that the work being undertaken carries a collective responsibility. Once it was established, through tutorial sessions, that most groups had grasped the essence of how to progress in their work, this was then achieved by notifying all students that, in the next class, individuals will be selected to report on the progress in each group. In the next class, a single student was then randomly selected from each group and asked to fill out percentile achievement rates on a conceptual flow chart (layout) of the steps required to achieve the overall project submission (Figure 3). The result was then shared and discussed with all the other members of the other group and used to assist them in identifying where a more concerted effort was needed.
- "Face-to-face promotive interaction": Each student needs to be actively involved and contribute to the overall activity in the group. This not only optimizes the working of the whole group but allows individuals to effectively develop their

team working skills. Based on the overall size of work required to achieve the case study, and the time scale available, the class (of twenty-five students) was divided into six groups, with students free to decide the individual membership of their teams. During tutorial sessions it was observed that some groups arranged themselves by sitting either side of tables, thus faced each other as they work. Conversely, other students seated themselves in a linear fashion (along tables). It was noted that in some instances students seated at the fringes, in groups using a linear seating layout, seemed less involved in discussions. The class was therefore asked to revise their seating arrangement and to select one where they faced each other as they discussed and worked together.

- "Group processing": By functioning as a facilitator, the teacher can provide the opportunity for each group to self-reflect on their performance and how to best improve this. In this regard, a single questionnaire was given to each group that required a (collective) response to the two questions. The first question asked the group to "list three issues (actions, activities, work techniques, etc) your group is doing well as you work on your case study". The second question required the group to "list one issue (action, activity, work technique, etc) which your group can improve on as you work on the case study". The returned questionnaires were then discussed with each group.

Consequential Observations

In addition to the aforementioned questionnaire, designed to allow groups to conduct their own critical self-assessment, other surveys were also designed to gauge student views on the teaching approaches (and research links) adopted during the radiator design case study. Table 2 shows the questions included. Figure 4 shows the results of these surveys. In each case students were confronted with a number of questions and required to respond with a numeric answer on a scale from zero to ten. Meanings of 'zero' and 'ten' scores were also explained. In reporting the findings of these surveys, the average score from each question is indicated.

Figure 4a shows the results of a survey conducted at the very start of the five-week case study and before any lectures were delivered. The survey measured the level of student exposure to PBL and the teaching-research nexus thus far. In particular, Question 1 sought to identify student's views on the teaching approach of combining fundamental knowledge alongside specific product design, in design oriented courses. Question 2 queried students on the level of PBL they had previously experienced. Finally, Question 3 queried students on whether they had experienced research outcomes being included into class material. This is designed to probe whether there needs to be more inclusion of *research* in class teaching (Hattie and Marsh, 1996). Overall results derived from the three questions (above) indicated a strong preference for design oriented courses targeting well defined products. The responses also showed that additional 'space' for curricula improvement existed when it came to the use of PBL in undergraduate learning as well as for the inclusion of research outcomes into teaching material.

Table 2 and Figure 4b shows questions and the results of a second survey conducted at the end of the five-week course; after PBL and the teaching-research nexus were applied. Question 1 gauged whether students considered that a teaching-research nexus improved understanding of core engineering subjects and their relevance to practical engineering. Question 2 tested whether a teaching-research nexus can effectively draw more students into (engineering) postgraduate study. The last item in this survey, Question 3 repeated Question 1

in the first survey (Figure 4a). This was intended to test how the overall techniques applied across the five weeks of the (radiator design) case study compared to other learning experiences.

Based on the replies to these three questions, it can be generally deduced that a teaching-research nexus beneficially affects undergraduate learning and that it can have some positive impact into recruiting students for postgraduate study. Such results also support the view that teaching should not merely provide students with basic knowledge, but also go the further step of inspiring students to undertake postgraduate study (Neumann, 1992). With regards to how this PBL (radiator design) compared to other learning experiences, the scores were slightly higher than those in the first survey (Figure 4a). This may be taken to generally indicate that the described case was as popular or better than other PBL that students had experienced. One aspect that was not investigated (here) but which may have some bearing on the overall effectiveness of the individuals and groups to benefit from, and function within, the multi-disciplined PBL environment is for the teacher to attempt to achieve some better "balancing" of each work group. As a starting point, this may be done based on (non-identifiable) student registration numbers and by considering overall academic standing (strength) as well as the stage of individual group members within their four year engineering degree. This aspect may be considered in further studies, however is believed that the self-formed group process did not impact on the findings presented in this paper.

| | Test Issue | Reply Scores |
|--|---|---|
| Pre-Learning Survey (No. 1) | Q.1 Do you think that combining (a specific) product design (e.g., radiator) along with coverage of the fundamental theory (e.g., heat transfer) is a good way of improving understanding in design oriented courses? | 'zero' indicates that it was a very bad idea, 'ten' indicates that it was a very good idea. |
| | Q.2 In the process of receiving your engineering education, indicate your level of exposure (familiarity with) the use of Problem Based Learning within undergraduate engineering classes at UTAs? | 'zero' indicates that they had not experienced PBL, 'ten' indicates that they had experienced PBL. |
| | Q.3 In the process of receiving your engineering education, indicate your level of exposure (familiarity with) to knowledge derived from textbooks being reinforced with outcomes of research investigations during classes? | 'zero' indicated that they had only received teaching material from textbooks, 'ten' indicated that they had received a lot of content derived from both textbooks and research investigations. |
| Post-Learning Survey (No. 2) | Q.1 Did the inclusion of research results into the lectures or the design submissions expand your awareness of how the fundamental knowledge you are studying in engineering impacts on real life engineering applications? | 'zero' to indicate that this was not helpful, 'ten' to indicate that this was very helpful. |
| | Q.2 Did the inclusion of research results into the overall learning experience make you more aware of what postgraduate research (in engineering) might be about? | 'zero' indicates that it had no impact, 'ten' indicated that it had a positive impact. |
| | Q.3 Do you think that combining (a specific) product design (e.g., radiator) along with coverage of fundamental theory (e.g., heat transfer) is a good way of improving understanding in design oriented courses? | 'zero' indicates that it was a very bad idea, 'ten' indicates that it was a very good idea. |
| Table 2 Student survey questions and response scores. | | |

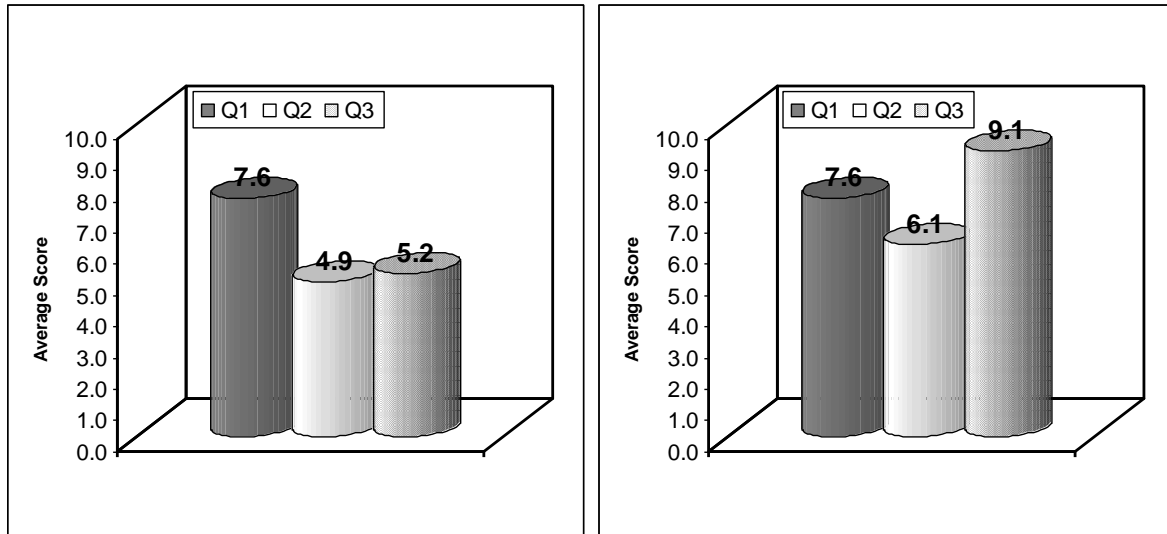


Fig 4: Results of student surveys. Fig4a (left): first (pre-learning) questionnaire (18 respondents). Fig4b (right): last (post-learning) questionnaire (8 respondents) (refer to Table 2).

Discussion

The paper describes a group based PBL approach used in the teaching of a design oriented unit. To exemplify how the teaching-research nexus can directly impact on student learning, lecture material was augmented with outcomes from relevant studies in the field. Despite the short duration of the course, a number of simple and specific actions were applied to improve the team working ability of both groups and individuals. Surveys indicated that the teaching methods implemented were viewed positively by students in that they allowed a better appreciation of the relevance of core engineering subjects and provided a reasonably (positive) motivation to pursue post-graduate study. Student responses also indicate a strong preference for design oriented courses to be more focussed around product design. Outcomes from the last survey also suggest that students experience some form of teaching-research nexus during their studies as has been reported in other studies (Neumann, 1994).

In conclusion, students not only achieved the desired design tasks but also augmented the outcomes with results from recent research and findings. Students (enthusiastically) discussed such issues during their presentations and elaborated as to how some findings impacted on the heat exchange process. The overall success of the approach reinforces the call for an increase in the interaction between teaching and research as well as the formulation of student works which promote a deeper learning experience (Hattie & Marsh, 1996). From an academic perspective, the inclusion of research results into the lecture material also meant that teaching became a much more enjoyable 'task' since it meant keeping up with recent (research) literature, whilst at the same time, being active in teaching. Hence, lecture preparation time also contributed to research and literature awareness. This is of particular significance for academics with primarily research-oriented positions, but who retain some teaching load, as is the case for the first author of this paper who is a post doctoral research fellow.

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