INTERNATIONAL CONFERENCE ON ENGINEERING AND PRODUCT DESIGN EDUCATION
10-11 SEPTEMBER 2020, VIA DESIGN, VIA UNIVERSITY COLLEGE, HERNING, DENMARK

PROBLEM-BASED LEARNING IN INTRODUCTORY THERMODYNAMICS AND FLUID MECHANICS

Euan COUTTS
University of Canterbury, New Zealand

ABSTRACT

Problem-based learning (PBL) is a pedagogical approach which aims to create engaged and thorough long-term learning. Often achieved by setting problems centred around a challenge encountered in a discipline representative of a “real world” challenge. In the process of creating a new school of product design (SoPD) and associated degree programme at the University of Canterbury in New Zealand a PBL approach was adopted for a new course in fluid dynamics and thermodynamics, titled “Thermofluids”. Intended to provide students undertaking product design degrees sufficient understanding and appreciation of the material to apply theory to make informed design decisions when dealing with design challenges related to these areas. The school wished to take a novel approach to ensure that students would retain their understanding rather than a more essentialist pedagogical approach to teaching and assessment alone. The first task, to demonstrate their understanding of basic fluid dynamics, was to design and build a “waterclock”. A fluid driven means of marking the passage of time. The second task, to demonstrate their understanding of basic thermodynamics, was to design and build a “solar oven”. PBL challenges are typically open ended and intend to place the students at the centre of the process with educators serving as guiding hands rather than providing prescriptive instruction. The brief for each of these PBL challenges was kept deliberately open in line with PBL theory, the intention being for the students to determine their own parameters for success of the endeavour. However, some alterations were required regarding criteria for the tasks. Important to note that it was the absence of prescriptive criteria which presented an issue, not prescriptive instruction. The various reasons for this are discussed in the paper. Upon completion of the class students were asked to provide a class evaluation. Without prompting the PBL challenges were highlighted as a key positive of the class with students providing commentary that the challenges made the theory feel real and assisted with their understanding of the theory and helped them to prepare for the exam. The paper explores the nature of the PBL pedagogical approach and reflects critically upon the process in this class as a case study, providing insight and proposing theories thereon for further study.

Keywords: Problem-based learning, thermodynamics, fluid mechanics, engineering education, design education

1 INTRODUCTION

Thermodynamics and fluid mechanics are cornerstone subjects within engineering degrees. In the process of creating a new School of Product Design (SoPD) within the college of engineering at the University of Canterbury (UC) in New Zealand it was determined that as part of the more holistic and practical approach to product design the new school encapsulates these subjects should be a core element. Accordingly, a bespoke class titled “Thermofluids” was created. This class intended to provide students undertaking product design degrees sufficient understanding and appreciation of the material in relation to their ongoing degrees and an ability to apply theory to make informed design decisions when dealing with design challenges related to these areas. The material contained within this class traditionally falls within the remit of mechanical engineering and can often create unease for students in other departments, especially design. Students, particularly those who are not initially confident in mathematics, may be intimidated and fail to engage proactively with the material. This manifests in a variety of fashions ranging from quiet disengagement with the material (until absolutely necessary at points of assessment) to outright obstinate rebuttal of the material; such students may decry “I don’t see how I will ever use this and it’s not what I want to do in my career”. In either case students run the risk of underperforming in a class which is very fundamental to the disciplines of both design and engineering due to a lack of engagement, preparation and self-study throughout the class. Accordingly, in the process of designing this class the author sought to explore various pedagogical approaches in order to ensure students engage continuously throughout the class and to foster enthusiasm that thermofluids is indeed not only fundamental to the students chosen discipline but additionally of immense practical benefit in achieving successful design outcomes.

This raises the question of how to teach and assess this material at a tertiary level considering the above most effectively. The subject, and especially the definition, of effective tertiary teaching is one of debate. This can be considered from a variety of perspectives; from an educational philosophy perspective such as essentialist teaching versus inquiry lead teaching or from a more practical sense about how best to execute such philosophies. However, even within this range there is seldom consensual agreement, and indeed in many cases outright contradiction. Considering this ongoing debate, how might teaching academics attempt to reconcile the most appropriate elements and mitigate the inappropriate?

In a recent investigation, through a series of consultations with tertiary teachers, into what constitutes excellent tertiary teaching (in a New Zealand setting) Kane, Sandretto [1] identified “excellence” though various metrics: what these teachers “say” about their teaching practices and compared this with what they “do” in practice, as frequently these factors are not always consistent. They concluded that it would appear that effective tertiary teaching consists of dimensions not only pertaining to knowledge of the subject in question but the context in which this occurs, the manner in which it is carried out and the underlying motivations for the above. There are many such analogous models indicating the multidimensional nature of tertiary education. Often presenting some level of consistently, such as the work of Young and Shaw [2] who, similar to Kane, Sandretto [1], propose six dimensions of effective teaching; value of the course, motivating students to do their best, comfortable learning atmosphere, course organization, effective communication, and concern for student learning. Many other guides and lists abound [3, 4]. While there is certainly validity to much of these models consisting of various dimensions, factors or concerns (terminology is mixed and at times used synonymously) are not universal. Criticisms of attempts to distil such a complex phenomenon as “effective tertiary teaching” down into analogies, lists and models are that there is no true one-size-fits-all model. Indeed it is frequently argued that context is critical [5] and that a synergy of such dimensions must be at play. Effective tertiary teachers should make use of appropriate methods as contexts would require. The debate surrounding effective tertiary teaching is unlikely to reach resounding consensual conclusion soon, but what of the practical methods used to achieve effective tertiary teaching, or its constituent dimensions? There are as many methods as there are subjects in tertiary teaching.

What strikes the author as a key commonality across all these various authors and approaches is the intention of placing the student at the centre of teaching. In places arguing for an almost Socratic method, as opposed to a more traditional (arguably increasingly outdated) didactic method. An approach intended to subtly prompt students to arrive at their own conclusions about a subject or problem, indeed the approach is very problem based. Although it could be argued that when students may be almost entirely novice in a given subject area there are some conceptually difficult barriers to overcome which students may not be able to achieve on their own, or even in a peer supported environment. This would speak to the need to be prepared to be flexible in one’s approach, rather than follow hard and fast rules when implementing a teaching method. These points are consistent with that of attempting to fulfil the role of a “More Knowledgeable Other” (MKO) to a student or group of students to use the terminology of Vygotsky [6] and referred to by McLeod [7]. According to these theories a MKO is critical to assist a student in crossing through a given “Zone of Proximal Development” (ZPD), a term which describes a conceptual transitionary space between tasks which a student may undertake autonomously and tasks with they cannot in relation to a given discipline. In many cases as tertiary teachers we attempt to dynamically and systematically scaffold ways for students to navigate these ZPDs in any number of settings, be it lecture based classrooms, tutorial groups, practical labs or supervision meetings. In such settings forethought regarding what stage a student may be at, then determining what types of advice or activities might be helpful to assist a student in transitioning between their known skills to a higher level of mastery of certain aspects of a given discipline. With the above in mind the class goal, learning objectives and intended assessment and feedback mechanisms were drafted in keeping with ubiquitous teaching scaffolding of constructive alignment as championed by Biggs and Tang [8].

The PBL approach has been successful in establishing a sense of “real world” authenticity to the material being taught. There is much ongoing debate in tertiary education regarding perceived lack of engagement considering readily available and convenient online digital content; it is interesting to consider if PBL could represent an approach to compliment such content. Could PBL help to address questions surrounding some students seeking a "path of least resistance", oftentimes with the students who require the most support. Particularly in disciplines as practical and vocational as design and engineering; for instance, a student may study the operations of a lathe, but it would be bold to let a student operate one having studied only theory and online representations. Employment of PBL may also be a mode of attempting to address the phenomenon of "credit counting" or "mark seeking" behaviour amongst students. Such terms refer to the practice amongst some students of prioritizing, sometimes dramatically, how they proportion or spend their time engaged with academic activities in relation to the number of marks or the frequency of marking associated with a particular class. In the case of theory-based material for instance, if the marks are only awarded by means of a final exam, some students will only engage with that material with their perceived minimal effort or time commitment until necessary. The rest of their time will be spent on other tasks where marks are more readily available or may be dispersed throughout a semester or academic year. It is hoped that the employment of PBL tasks would ensure a more consistent engagement on a continual basis through the tangible design and build process involved in the tasks set for this class. More so than, for instance, grading for attendance approaches. Which have drawn criticism for attributing to escalation of assessment and at worst been referred to as a so called "arms race" of assessment [9].

2 PROBLEM BASED LEARNING IN INTRODCUTORY THERMODYANMICS AND FLUID MECHANICS

PBL is a pedagogical approach to teaching and learning which aims to create engaged and thorough long term learning amongst students; "Problem-Based Learning (PBL) is an instructional pedagogy founded on the promises of knowledge construction by inquiry" [10]. This is achieved by setting problems centred around a challenge encountered in a discipline, often representative of a "real world" challenge. The approach originated in the law profession, became popular in medicine and has been adopted by many tertiary education institutions in a variety of disciplines [11]. In the author's own experience in the process of evolving a new school of product design and associated degree programme various pedagogical options were considered for the execution of a new course in introductory fluid mechanics and thermodynamics, for which the author is responsible. A composite body of material would be covered in the class and a variety of assessment modes were to be employed to assess students understanding. The author was interested in ascertaining if the PBL approach could be applied to this engineering material and theory. While this was new to the SoPD at UC there have been other endeavours to do so by various means [10, 12].

A series of problem-based tasks were designed which would require the students to demonstrate their understanding of the theory in application in small teams; 62 students in total working in teams of 4. An example of the typical work carried out by students in these tasks is demonstrated in *Figure **1***. The first task, to demonstrate their understanding of basic fluid dynamics, was to design and build a "waterclock". A fluid driven means of marking the passage of time utilizing some stock components including a small pump and a small discretionary budget. The second task, to demonstrate their understanding of basic thermodynamics, was to design and build a "solar oven". A method of cooking a food stuff to a required temperature utilizing sunlight, again with a small discretionary budget. PBL challenges are typically open ended and intend to place the students at the centre of the process with educators serving as guiding hands rather than providing prescriptive instruction [13]. The intention being to provide a guided mix of information-orientated teaching in the form of the supporting class lectures and discovery-orientated teaching in the practical design and build PBL tasks. This approach was intended to ensure that students could cross the ZPD with support and guidance.

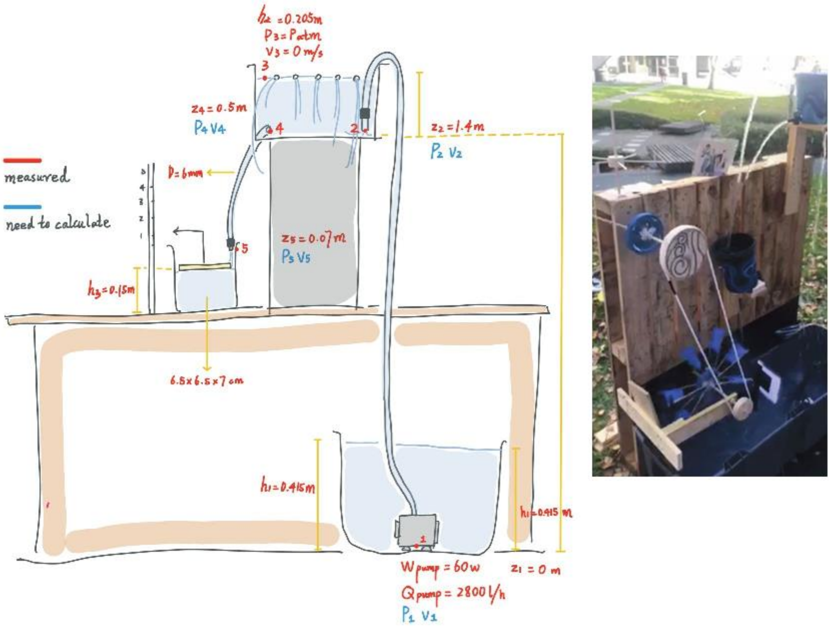

Figure 1. Example of typical work undertaken by students in the PBL water clock task

The brief for each of these PBL challenges was kept deliberately open, the intention being for the students to determine their own parameters for success of the endeavour. However, the students struggled with the absence of prescriptive criteria (important to note that it was the absence of prescriptive criteria which presented an issue, not prescriptive instruction). Early in the first water clock challenge it became apparent that more criteria would be required for the process to be successful. The PBL challenges comprised 40% of the assessment for the class, accompanied by a 40% examination and 20% assessed interim tutorial activities. Importantly the students were required to physically produce their designs, changing the way they engaged with the material from theoretical to practical application in support of the theory. Students were additionally asked to submit a report upon the process following completion, including explanations of how their designs related to the theory covered in the class lectures. Upon completion of the class students were asked to provide a class evaluation. Without prompting the PBL challenges were highlighted as a key positive of the class with students providing commentary that the challenges made the theory feel real and assisted with their understanding of the theory and indirectly helped them to prepare for the exam and interim quizzes which ran throughout the semester. It is additionally worth noting that the sessions associated with the PBL challenges received higher attendance than other sessions. Below are excerpts from the class evaluation related to the PBL challenges:

- “Design and build tasks are so great. Perfect for this course!”
- “They were good - because they are practical assessments rather than purely theory”
- “I like where we have the chance to test the theory by build water clock and solar oven. It definitely help me to learn a lot and experiment what works and what doesn’t” [sic]

3 DISCUSSION

Overall, the students were enthusiastic about the tasks and reported upon class completion that the PBL tasks helped to prepare for the class final exam and made the theory “real”. The PBL tasks were well suited to demonstrating to students how theory such as Bernoulli’s equation or the principles of specific heat, to name a few of the concepts covered in the class, manifested in a real fashion. Such theory is really developing an understanding of how various parameters relate to one another according to principles and mathematical expressions. Were this to be presented in a purely lecture and tutorial-based fashion it is doubtful if students would have grasped the concepts as well as they did through this approach. There is something much more memorable and relatable about varying the diameter of a nozzle, for instance, and witnessing the result than simply studying the theory alone.

However, there are subtleties to be discussed. For the first PBL task, the waterclock, the intention to leave the determination of criteria for success to students themselves, while marching in step with theory on PBL tasks, met with some resistance from the student body. Students felt that is was “not fair” or “unreasonable” to have them conduct work for which a large chunk of their grade would be determined without knowing on what basis this would be graded – despite allocating significant lecture time to attempt to explain that students would be aware of their success criteria once they had provided them. Ultimately a set of specific criteria, but still suitably broad, was drafted. This was conducted with class staff eliciting the criteria from the student body in a dedicated session during one of the weekly lectures, in principle there is no reason to assume that these criteria would have been any different than those the students would have arrived at without the class staff facilitating, which in itself is an interesting phenomenon. There is much to reflect upon from this sequence of events, perhaps explanations on how the task would be graded were not clear or perhaps students felt that there may be some nefarious attempt to “trick” them somehow, a suspicion that somehow, behind the scenes, there was some list of “correct” criteria which the students had to somehow intuitively hit. Perhaps further still students are sceptical or uneasy with this level of control over their own assessed performance, this may be related to prior or parallel experiences in other classes or assessment in tertiary or other educational environments. The intention had been to mark the students against the criteria they themselves drafted but this message did not appear to be received, perhaps for the reasons above. The author tentatively suggests that this is a matter of trying to strike a balance between providing sufficient guidance without becoming vague; the author would consider this perhaps to be analogous to the phenomenon of ZPL and the expectation from one party of another, perhaps prior experience has created an engrained expectation that a MKO will provide answers and deviating from this can feel uncomfortable. Reflecting upon and learning from this experience revisions will be made to future iterations of the tasks set. The importance of being able to be flexible in new approaches was discussed earlier in the paper. Indeed in the case of the solar oven task which followed the water clock several options of criteria for success of the activity were presented by class staff, the students were then polled in class as to which options they preferred. This appeared to resonate with the students to a greater extent, with feedback upon class completion to that effect. Having a stake in the formalization of the assessment of the tasks had the added benefit of providing the students with a sense of investment in the activities they were undertaking, with many of the students commenting upon class completion that the feedback was very clear, this could possibly be in part due to the increased sense of investment and to a certain degree agency which this approach provided the students with. Such activities and endeavouring to ensure that students not only understand but additionally truly feel that they are the principal stakeholders in their education is very powerful in driving engagement in class.

4 CONCLUSION

This work represents a novel problem-based learning method of teaching introductory theory in thermodynamics and fluid mechanics, which would be of relevance to teachers and academics involved in teaching in these areas. In a broader sense it would be relevant to those involved in education interested in the PBL approach. Reflecting upon the reported success of the approach it is reasonable to assume that without the PBL tasks those sessions which would otherwise have been traditional theory-based lectures would also have received less engagement from students. Beyond the pedagogical discussion covered there are unfortunately challenges with adopting the PBL approach in such a class. Without doubt this approach does require more time investment by class staff than simply developing traditional lectures, in the first instance in any case. Due to the nature of the tasks selected in this class there was a physical and financial investment required, perhaps this could be mitigated by changing the nature of the task but changing the manner in which the students engage with the material (going from theory to practical application) is a key aspect of the success of this approach. Concerns remain in the authors mind regarding the “scalability” of such tasks, given increasing class sizes, the feasibility and costs of such practical PBL tasks may become problematic. It is reasonable to conclude that the PBL tasks did drive greater engagement, agency and investment from the students undertaking the class. This has very much resonated with students, more so than traditional theory-based sessions and assessment alone.

REFERENCES

[1] Kane, R., Sandretto, S. and Heath, C. J. H. E., *An investigation into excellent tertiary teaching: Emphasising reflective practice*. 2004. 47(3): p. 283-310.

[2] Young, S. and Shaw, D. G., *Profiles of effective college and university teachers*. The Journal of Higher Education, 1999. 70(6): p. 670-686.

[3] Kember, D. and McNaught, C., *Enhancing university teaching: Lessons from research into award-winning teachers*. 2007: Routledge.

[4] Marsh, H. W. and Roche, L., *The use of students' evaluations of university teaching to improve teaching effectiveness*. Canberra: Australian Government Publishing Service, 1994.

[5] Quinlan, K. M., *Commonalities and controversy in context: A study of academic historians' educational beliefs*. Teaching and Teacher Education, 1999. 15(4): p. 447-463.

[6] Vygotsky, L. S., *Mind in society: The development of higher psychological processes*. 1980: Harvard university press.

[7] McLeod, S. A. *What Is the zone of proximal development?* Simply psychology: Psychology. 2019 [cited 2020 March 2020]; Available from: https://www.simplypsychology.org/Zone-of-Proximal-Development.html.

[8] Biggs, J. and Tang, C., *Teaching for Quality Learning at University: What the Student Does (3rd Edition)*. 2007, Buckingham, UNITED KINGDOM: McGraw-Hill Education.

[9] Harland, T., et al., A*n assessment arms race and its fallout: high-stakes grading and the case for slow scholarship*. Assessment & Evaluation in Higher Education, 2015. 40(4): p. 528-541.

[10] Nasr, K. and Ramadan, B. J., *Implementation of problem-based learning into engineering thermodynamics*. 2005. 10: p. 1.

[11] Barrows, H. S., *Problem-based learning in medicine and beyond: A brief overview*. New Directions for Teaching and Learning, 1996. 1996(68): p. 3-12.

[12] Tatar, E. and Oktay, M., *The effectiveness of problem-based learning on teaching the first law of thermodynamics*. Research in Science & Technological Education, 2011. 29(3): p. 315-332.

[13] O'Steen, B. and Spronken-Smith, R., *Inquiry-guided learning in New Zealand: From an appetizer to an entrée.* New Directions for Teaching and Learning, 2012. 2012(129): p. 39-49.