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Using an informal competitive practical to stimulate links between the theoretical and practical in fluid mechanics: A case study in non-assessment driven learning approaches

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A B S T R A C T

This study outlines a practical intervention in a second-year fluid mechanics course. The practical was designed using the framework of Legitimation Code Theory, with the aim of stimulating active links between the theoretical and practical (in this case pump and piping networks, head loss and application of the energy equation), through a group-based competitive, informal, interactive learning event. The effect on students' perceptions and anxiety were recorded, and it was seen that students' perceptions of workload, anxiety and time pressure decreased. Substantial evidence of cumulative learning was noted, both during the practical session, as well as in student responses. And while the data do not conclusively elucidate the extent and timeframe over which this benefits the students' results, what is clear is that participants both critically engaged and were enriched by the practical. The project lays the foundation for similar theory- and application-linking practicals based on a non-assessment paradigm.

1. Introduction

In the face of increasing 21st century engineering complexity (UNESCO, 2010) and specialisation, engineering curricula are being pressurised to 'face both ways' (Barnett, 2006): towards the theoretical knowledge base and increasingly complex application contexts. Thus, one sees more theory and more practice being introduced into an already full curriculum. At the same time, however, high failure and dropout rates (Council for Higher Education, 2013), as well as industry complaints about graduate inability to 'apply knowledge' (Griesel and Parker, 2009) suggest that the theory–practice divide needs attention if we are to improve engineering education. Muller (2009), citing Becher and Parry (2005) refers to the distinction between 'know why' (theory) and 'know how' (practice). This relationship is crucial in curricula, and linking these in the students' minds develops the knowledge base necessary to be a good professional engineer.

It is common in university engineering education to focus teaching heavily on the theoretical, examine on the basis of worked examples and (for instance) show videos of physical examples. Indeed, in well-resourced institutions, it is common to find technology-based learning platforms (Rooch et al., 2016): providing access to YouTube videos, recorded class or laboratory demonstrations, and even simulation software

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such as that used by Gynnild et al. (2007). These approaches are designed to demonstrate the application of theory to practical contexts, but often essentially represent passive activities for the student—a learning mode which does not foster deep or long term learning (Najdanovic-Visak, 2017). Unfortunately, this robs the student of an important linkage between what is fundamentally an applied science and the theory that is rigorously covered in class.

A space for students to experience and develop an intuitive feel for the theoretical material is needed in developing the students' understanding and allowing the student to more fully undergo cumulative learning (Maton, 2013). Kolb's experiential learning theory (2014) expands on this notion: he sees holistic learning as the integration of experience, perception, cognition and behaviour. Indeed, work by Abdel-Salam et al. (2006) in a fluid mechanics practical context, and Chen et al. (2016), in their experiential practicals, illustrates that active participation is key in learning experiences. For this reason, laboratory practicals remain an integral part of university engineering curricula. However, the prevalence of assessment-driven learning in the practical context often results in the students not critically engaging with the equipment and demonstrated phenomena, but rather opting for a superficial and targeted learning approach—taking their measurements and samples, with little deep understanding being generated (Chin and Brown, 2000; Louw, 2016; Ram, 1999; Young et al., 2006). Moreover, the use of competition, and team work, has been suggested to improve learning outcomes, motivation, student participation and stimulation (Delgado and Fonseca-Mora, 2010; Lefebvre et al., 2009; Zou and Ko, 2012).

In addition to the importance of bridging the divide between the theoretical and the practical, another important parameter in student success is their attitude: their motivation, anxiety, and perception of ability (Jones et al., 2010; Savage et al., 2011). Not only is their attitude linked to success, but it is often an indicator of the type of learning they are likely to pursue: deep, strategic or surface (Entwistle, 2000). Our students experience great pressure during the course of their studies, and those students without a positive outlook towards their work, the course, and the material are at a disadvantage (Brown et al., 2015; Fadali et al., 2004), and less likely to engage in 'deep' learning.

The intervention outlined in this research aimed to enable deep learning, cause the fundamental connection of theory to practice and to stimulate student interest, engagement and motivation through a group-based competitive, informal, problem solving, interactive learning event. In order to succeed the students needed to grapple with, understand, and apply the theory of pump curves, pumping networks and pressure losses, to achieve a practical solution to the open-ended (but constrained) problem. We hoped to, firstly, positively affect student attitudes through the practical, and secondly to demonstrate that a successful, learning-rich practical environment can be achieved using a non-assessment driven philosophy.

2. Context

This study was conducted within the second year of a four-year chemical engineering degree programme at a research-intensive traditional university in South Africa. The programme is International Engineering Alliance (IEA)-aligned and accredited by the Engineering Council of South Africa, a signatory of the Washington accord. As such, while there are context and societally specific aspects within this programme, research conducted with these cohorts is likely to be broadly applicable to other global institutions and engineering programmes. Indeed, the challenges facing many of the world's engineering educators are the very same that we experience—needing to teach ever more content, within smaller time-frames, to larger classes.

The course in which we ran this practical instructs second year chemical engineering students in the fundamentals of fluid mechanics. The course deals both with conceptual, more abstract topics such as the mathematical description of flow using the Navier–Stokes equations, and with more practical calculations and topics, for example, pressure drop calculations, design and calculations around piping networks and pump sizing.

However, many students have had little opportunity to interact with the types of equipment that make up the most basic elements of chemical plants. They have not seen a ball-valve, or considered the implications of fittings or material selection when constructing piping networks; they have little intuition when it comes to the effect of pipe size on pressure loss or how to correctly select a pump or connect pumps in networks to achieve required flow rates or pump heads. One way to overcome this gap is to expose the students to appropriate practicals.

The curriculum in the second year does include fluid mechanics practicals, where the students develop the operating curve for a pump, simulate cavitation, and determine the friction factors of various pipes and fittings. These practicals aid in filling the gap between knowledge and intuition, and help to bring the students' experience in line with learned theory. However, the practicals are set up in such a way that the students are very constrained in how they can engage with the equipment. They are instructed on how to vary the flow rate and measure the head developed, or shown incipient cavitation, but they have little opportunity to experiment, dismantle, reassemble, examine and generally experience the constituent equipment. Prior observation and assessment suggests that the absence of such an opportunity is much to their detriment and appears to manifest as inadequate linking of theory and potential application.

In addition, these practicals are assessed through written reports, and student interviews and anecdotal evidence suggest that students practice 'surface' and 'strategic' learning (Entwistle, 2000). They do not fully engage with the practical, but rather focus on taking only those readings, measurements and observations which will allow them to fulfil their report writing task—a task they find onerous and frustrating, partially since they have little deep understanding of the systems that they are now writing about. The *status quo* is therefore failing to enable deep learning, failing to cause the fundamental connection of theory to practice and failing to stimulate student interest, engagement and motivation.

This lack of deep learning then manifests itself either as poor throughput rates for the module (e.g., faculty statistics show that over the period 2011–2015, this module ranked 9th highest for failure rate among 41 modules in the 4-year Chemical Engineering programme at the university) or further into the programme; for instance where final year students are unable to link the theory they have learnt over the course of the programme with practice when they need to work in the laboratory independently during their final research project.

In order to appropriately design practicals, interventions, and teaching methodologies which address the issues highlighted above, a theoretical framework to conceptualise student learning is needed. One framework for understanding learning that has gained increasing prominence in the field of the sociology of education is Legitimation Code Theory (Maton, 2013), which has numerous dimensions. Semantics is one such dimension, which includes the concept of *semantic gravity* (SG) where one differentiates between concepts that are more abstract (weaker SG) and those that are dependent on actual real world or teaching contexts (stronger SG). If learning only occurs in the latter, there is no possibility of developing generalised principles. On the other hand, much university learning appears to be confined to the former: decontextualised and abstract. It is the ability to link the abstract to the practical in a manner that demonstrates informed understanding that results not only in what is called 'cumulative learning' (Maton, 2009), but also in the development of a well-equipped professional engineer.

3. Methodology

In order to address the project aims, the following approach was adopted: Students (n = 90) were handed an entry questionnaire at the beginning of the module, which asked them to rate their perceptions regarding specific aspects of the module, their anxiety levels and perceived time constraints (81 responded). The students were then required to perform an open-ended practical exercise, of which the theory had already been taught during formal lectures. The final phase entailed an exit questionnaire where perceptions were again evaluated, and where students were asked to comment on their experiences of the practical exercise and how it impacted their understanding of the theory taught during lectures (47 responded).

Response to the questionnaires was voluntary, whilst attendance of the practical exercise was compulsory, where non-attendance was penalised by the student being awarded 0 for an associated tutorial test if they did not attend both the test and practical. Questionnaires were not completed as anonymous responses, thereby enabling the monitoring of performance of individual students within the module; however, only the contributing authors had access to data linked to individuals. Ethical clearance for this project was granted through the University's ethics committee, and data were collected strictly according to university ethics protocols, after consent to use the data for research was obtained from participants.

3.1. *Entry questionnaire*

The entry questionnaire comprised 8 questions, 6 of which asked participants to rank certain aspects on a scale of 1–4. Among these first 6 questions the following aspects in the students' perceptions of the module and themselves were investigated: anxiety for the module (with opportunity to comment on specific causes thereof), expected overall module difficulty, expected time constraints in the module, expected difficulty of specifically the assignments and tutorials, level of motivation for the course, and the level of prior hands-on experience of fluid-flow equipment. The seventh question asked whether it was the participant's first time of taking the module, while the final question asked the participants to rank their knowledge of specific aspects of fluid flow on a scale of 1–3. Data captured from students who later deregistered from the module (for whichever reason), were removed from the data set. For a complete set of questions and the wording employed in the entry questionnaire, see Appendix A.

3.2. *Exit questionnaire*

The exit questionnaire also consisted of 8 questions, 4 of which asked participants to rank on a scale of 1–4, their level of anxiety and their perceptions on overall module difficulty, time constraints, and their level of motivation for the course, mirroring the entrance questionnaire. The remaining questions required a written response from participants, and asked for comment on the participants' experiences of the practical exercise, how the exercise impacted on their understanding (both general understanding of fluid mechanics and their understanding of specific topics and concepts in the module), the preferred order of completing the practical/tutorial test, and any general comments regarding the practical exercise. The complete set of questions and wording is provided in Appendix B.

3.3. *Practical exercise*

Based on the data obtained from the entry questionnaire, the class was divided into 20 teams of 4 or 5. Teams were divided such that the most 'positive' students were grouped together, the most 'negative' students were together, and the 'middle' students were put together. Positive students were grouped based on answers of Question 6 (regarding levels of motivation for the module): only responses of "very motivated" were considered as being positive. Negative students were also based on responses of question 6, along with students who did not complete the questionnaire (not completing the questionnaire was interpreted as a potential lack of motivation for the module and/or that the particular student shows a negative view toward the module). Responses of "Unmotivated", "Apathetic", or no answer were considered as being negative.

Research into complex problem solving suggests there are internal and external factors (Funke and Frensch, 1995) which affect the ability of the subject – in our case, the student – to engage with complex tasks. The internal subject factors include cognitive, and non-cognitive variables such as self-confidence, motivation and enjoyment (Funke and Frensch, 1995, p. 45). There are several challenges in analysing participant problem-solving processes and evaluating effective performance. Motivation can be a key determinant, and as such the participants in this study were divided into distinct categories according to levels of motivation expressed in the entry questionnaire. This separation of 'positive' and 'negative' groups enabled a more effective triangulation of the relationship between motivation, experience (feedback) and performance (assessment results).

Due to limitations in space and equipment, the class was divided into quarters (5 teams in quarter A, 5 in B, 5 in C and 5 in D). All groups had already been instructed in the theory necessary to complete the practical during prior lectures. Groups A and B wrote a tutorial test on the material before completing the practical exercise, while groups C and D completed the practical exercise prior to writing the tutorial test. Since only 5 groups could be accommodated at a time on the practical rig, there was some downtime for some students. Table 1 below shows the timelines for each group.

Table 1 – Designation of the different groups, and the order in which the practical exercise and the tutorial test were completed.

	Session 1	Session 2	Session 3	Session 4
Group A	Tutorial test		Practical	Free
Group B	Tutorial test		Free	Practical
Group C	Practical	Free	Tutorial test	
Group D	Free	Practical	Tutorial test	

3.4. *Practical set-up and performance*

None of the groups had prior knowledge of the practical exercise or the nature thereof, other than being informed that it is compulsory. Upon arrival at the practical setup, students were instructed to transport 70 L of water to a receiving container located 8 m higher than the starting point (up two flights of stairs), using the pumps, pipes and fittings issued. A competitive element was introduced by awarding two prizes for each group: one each for the team that either transported the required volume of water (i) fastest or (ii) most efficiently (i.e. used the least amount of electricity).

Each team was given two plastic 150-L containers, a 50-L container, three pumps (one pump with a maximum head 3.5 m and maximum volumetric flow rate 3000 L/h, and two identical pumps with a maximum head and volumetric flow rate of 7 m and 800 L/h respectively), pump curves for the pumps, various 1 m long pieces of pipe (25, 20, 16, 12 mm inner diameter), pipe fittings sufficient to enable construction of a wide range of piping system configurations, and a power meter. Each team was also given access to 2 clear plastic pipes of 12 and 20 mm inner diameter, which had been affixed to solid supports ascending the full height. These pipes constituted the majority of the total piping length of the system (approximately 90%), and teams had the freedom to choose to employ any of the two pipes, or utilise them simultaneously.

Each group was then given 25 min to experiment with different pump and piping network configurations, and to test flows, followed by 5 min to assemble the final preferred set-up. After final set-up, the competition was run and the fastest and most efficient team(s) were identified within each group.

The full exercise was video recorded, for post-practical analysis. In addition, a facilitator continuously circulated amongst the students to interpret (i) their levels of engagement, (ii) their demonstration of knowledge of theory and (iii) their application of knowledge to this open-ended problem. The facilitator was the same person for all groups, to keep constant their influence on the students.

3.5. *Data analysis*

Quantitative data analysis was performed on the results of the rating questions which were common to both questionnaires, i.e. rating anxiety, module difficulty, time constraints experienced in the module, and the students' motivation for the particular module. Data were analysed in two different ways: not participant-linked, and participant linked.

Not-linked analysis consisted of computing the mean of all responses for each of the four rating questions, for each questionnaire. For each question, the mean values were then compared statistically using a t-test, and differences were viewed to be statistically significant for $P < 0.05$.

The analysis of linked data was performed by tracking responses to the rating questions of individual participants, and determining the change in perception of these individuals between the entry and exit questionnaire. The change in perception for the individuals were then classified as Increased, Decreased or Unchanged for each question.

The qualitative data analysis was performed using the written responses received on the open-ended or discussion-type questions, to identify trends regarding interrogation of the *semantic range* (Maton, 2013) among candidates (the linking from theory to written to applied practical), and whether students were able to generalize lessons learnt during the practical to wider fluid mechanics principles. Key excerpts indicating significant trends are quoted in the discussion below.

4. Results and discussion

4.1. *Student perceptions*

The analysis of data not linked to individuals showed statistically significant changes in the overall perceptions of anxiety, module difficulty and module time constraints from the entry to exit questionnaire, but no significant change in overall motivation for the module. Fig. 1 depicts shifts in perception between the entry- and the exit-questionnaire. And while the data cannot conclusively point to the practical intervention as the reason for these shifts, it is clear that overall anxiety levels, perceived module difficulty and time constraints all decreased significantly, which are interpreted as positive shifts in perceptions.

Data analysis on the individual-linked results revealed similar patterns as observed for non-linked results (Fig. 2). The overwhelming majority of participants who reported changed perceptions showed decreased levels of anxiety, worry about time constraints and so forth, all relating to positive shifts in perception. For anxiety levels, perceived module difficulty and time constraints, the number of participants reporting positive shifts outnumbered those reporting negative shifts in perception. Student motivation showed no clear changes, and the majority of the largest grouping within that category are those who reported no change in motivation levels. The ratio of respondents reporting positive: negative shifts in perception were high and ranged from 16.5: 1 to 38: 1 for anxiety levels, module difficulty and time constraints, while for module motivation, the ratio decreased to 1.44: 1.

The fluid mechanics module in the Chemical Engineering programme is generally perceived as one of the more difficult modules in the programme. This is seen from student perceptions on anxiety and module difficulty at the beginning of the module, and it is backed up from Faculty statistics which generally indicate high failure rates in the module. The significant shift in student perception about the module difficulty is therefore seen as a very positive development, as student perception has been strongly linked to final performance before. Whether this shift in perception can be directly attributed to the practical exercise is not clear, as there were many factors that could have contributed to the observed shift over the course of the semester. Indeed, as the exit questionnaire was only answered by about 60% of the class, there may be an inherent bias in the data towards those students most likely to continue to attend class. A further aspect that should be acknowledged as a limitation in the analysis of these data is that the interpretation on shifts in perception might not be straightforward, as individual students could interpret the concepts alluded to in the questionnaires differently, or their own interpretation of the concepts may have

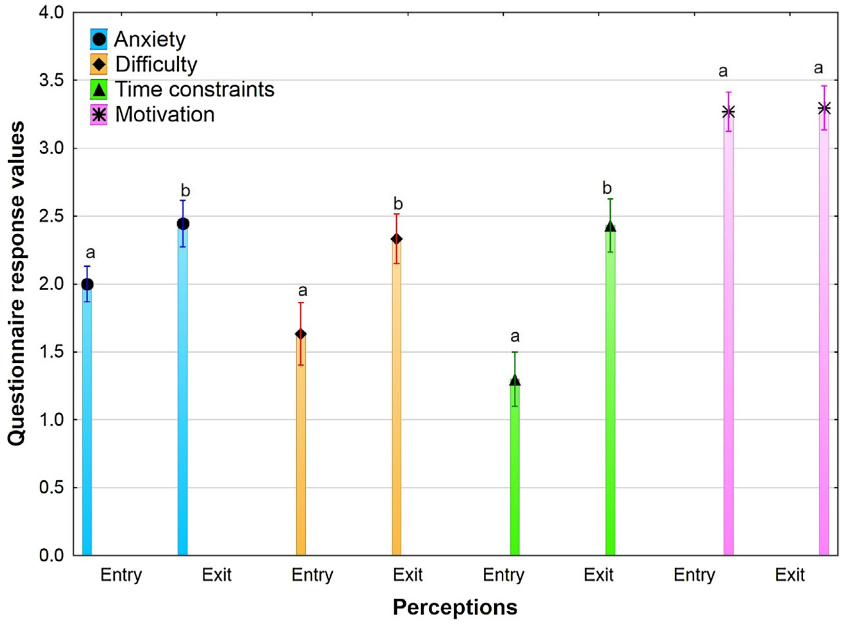

Fig. 1 – Change in perception of students as measured at the start and end of the module using the entry and exit questionnaires. The questionnaires were coded such that the responses convert numerically left to right—for example, question 1 of the entry questionnaire's responses have 'Very anxious' encoded as 1, and 'Very confident' as 4. Data are reported as mean ± 95% confidence intervals for the particular response. Different superscripts within a specific perception denote statistically significant differences. Note that increased questionnaire response values correspond to decreases in the particular perception (refer to Appendixes A and B).

changed in the time period between the entry and exit questionnaires. The interpretation of students' responses by the authors, and the subsequent grouping of students as being 'positive', 'negative' or 'neutral' may further not be entirely accurate due to differences in how responses are intended (by students) and how these are interpreted (by the authors). These factors may make it difficult to conclusively link the changed perceptions exclusively to the practical intervention; however, despite these potential limitations in the study, there are strong indications that the practical played a large role in the improvement of module perceptions, both from the student responses in the exit questionnaire, and from informal interaction with the participants after the practical. The quotes below demonstrate some typical responses on the exit questionnaire:

> 'The practical was motivating, it provided a positive and competitive atmosphere. At the same time it provided a glimpse of the important aspects in fluid flow.' — Mixed team, Group D

> 'I loved the practical session. It was exciting and enlightening. It allowed us to put theory into practice and let us think on our feet.' — Positive team, Group A

> 'I really enjoyed the practical. It was a hands-on demonstration of the work we studied. Made me feel more confident and interested in the work.' — Positive team, Group C

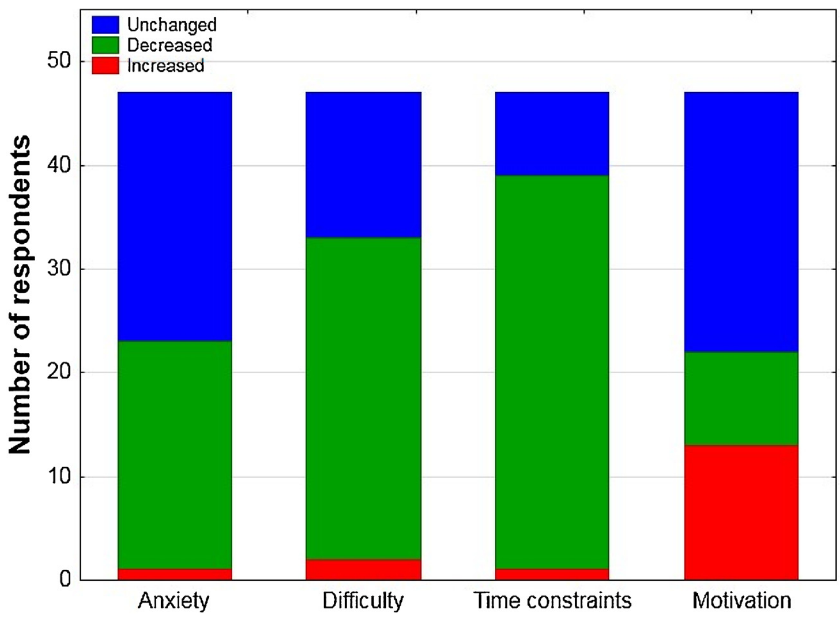

Fig. 2 – The number of respondents who reported no change, or an increase/decrease in perception.

'It was extremely helpful to get hands-on experience with some miniature pumping equipment. It helped increase my understanding and feel for pumping related problems.' — Negative team, Group C

The potential positive impact that improved perceptions can have on student performance should not be underestimated (Entwistle, 2000). Improved perceptions in particular modules have been shown to directly impact on student performance (Depaolo and Mclaren, 2006; Ferreira and Santoso, 2008). This has obvious positive implications for the particular module, however there is the further potential that improved perceptions of a module might to lead to an improved view of the whole programme and the students' learning environment, and consequently to better performance in the wider programme. The benefit that this may have to the overall learning experience of the students throughout their programme, are therefore well worth pursuing.

4.2. *Peer driven engagement*

Readers who are practitioners in higher education will recognise that for non-assessment based work, attendance and engagement is often poor. Experiences in the Engineering Faculty at the research site have shown this to be true, in practicals and experiential learning events similar to the one described in this study. Therefore, since this practical was not to be assessed, there needed to be a mechanism or driver to (i) ensure attendance and (ii) ensure engagement.

As is illustrated in Table 1, this practical ran concurrently with a tutorial test on this subject material, with the class split and rotated between practical and test throughout the afternoon. The class were informed that the practical would not be assessed, there would be no marks from or reports required from it. However, in order to be awarded marks from the tutorial test (which counted a small percentage towards their final mark), the students had to be present at the practical. This linking of lack of presence to a penalty was seen to be effective in ensuring attendance, as only one student opted to write the tutorial test but not attend the practical (that student was duly penalised). In fact, there was even one instance of a student who did not write the tutorial test (with an excusing sick note), but who did attend the practical.

However, attendance is necessary but not sufficient for engagement; and engagement is necessary (but not sufficient!) for learning. In assessment-driven learning, students are motivated to engage through the 'carrot' of marks awarded. However, experience in the practical course which complements this module shows that students very quickly revert to a superficial understanding of the practical's complexity—they simply record the values they believe they will need to write their report, with little regard for undergoing the learning intended by the practical. Louw (2016) observed and reported this as 'rote data collection followed by report writing'. Consequently, students do not actively participate in the learning opportunity provided by the practical experiments and no connection is made to taught theoretical concepts'.

In this practical, however, students were not motivated by assessment, but rather by the context of the event: they act within allocated groups, and are subject to competitive peer pressure to engage thoughtfully, actively, and accurately. The practical problem was structured in such a way that in order to succeed (and win one of the prizes—which the students thought to be chocolates, or some such trivial prize, but were actually fairly substantial monetary rewards), the students needed to apply the theory learnt in lectures. They would not simply stumble onto the correct result. It was noted by the facilitator, and later substantiated through examining the video footage, that this social pressure was so significant that almost all participants were actively engaging with the practical almost all of the time. Many respondents to the exit questionnaire referred to this pressure, mostly in a positive way:

'It was great. Everybody gave ideas and worked together' — Positive team, Group A

'Got to meet new people and hear how they are thinking. I liked the input, because what I missed they noticed.' — Positive team, Group C

'It was fun to share ideas with fellow students and devise a strategy to solve the problem.' — Negative team, Group C

The students' written responses show an indication of another key benefit of using practicals as a teaching methodology: the students help to teach each other the material, reinforce the concepts, and correct misunderstandings.

'It was really great. We could bounce ideas off each other to come to the best solution. And we were good at different things, like connecting pipes or positioning pumps or whatever.' — Mixed team, Group C

'It was nice to view how different people wanted to solve a problem and them challenging your thinking' — Mixed team, Group D

However, unsurprisingly, there were students who either battled to contribute to the team effort, or who were perceived as not engaging:

'I moderately enjoyed working in my group. However, some group members did not understand the theory of pumps as well as others. Explaining to them why some ideas would or would not work and conversing then wasted some time. Having other people to think together with, was great though.' — Positive team, Group A

'. . . some people don't participate.' — Negative team, Group D

'Not all members contribute as well and were perhaps a bit shy. Everyone was however included and assigned a "job"' — Mixed team, Group A

Not all of the 'experienced' social pressures were the same: each team had been formed either from positive students, negative students, or in-between students (on the basis of their answers to the entry questionnaire). The students in the positive or mixed groups engaged enthusiastically and productively; as an indication, 50% of prizes going to 'positive' groups, and 37.5% going to 'mixed' groups. The 'negative' groups also positively engaged, but they tended to take longer to reach a solution, and were more likely to attempt to implement an incorrect solution. It could be postulated that the positive group members experience a greater social pressure to engage than the negative groups, however, more insightful data capture and measurement is needed to elucidate whether this observed effect is a result of variations in peer pressure, student ability, student motivation, or some other factor.

4.3. *Building conceptual grasp*

The key focus of the practical was to assist in student learning; to facilitate a cognitive movement from theoretical to practical, and back up to generalised principles. Only two students who completed the exit questionnaire indicated through their responses that the practical did not help them, but each for a different reason. One student felt the practical theory was thoroughly covered in class:

> 'It's easy enough to theorize but it's not exactly smooth sailing when applying the knowledge.' — Negative team, Group B

However, another student demonstrated a disjuncture between his concept of 'theory' as experienced in the classroom and the application of that theory:

> '. . .I don't really understand how to do the practical part but I do get the theory.' — Mixed team, Group C

Nonetheless, a significant number of comments on their general understanding post-exercise demonstrates the students' own shift from the contextual (the practical) to the conceptual (relating the work back to the theory) where they explicitly link the experience to theory:

> 'One group used a large diameter pump that did not have enough head to get the water to the bucket. Seeing this made the problem more real and enhanced my understanding.' — Positive team, Group A

> 'I could see the way pumps work, especially what happens to the head and volumetric flow rate when pumps are connected in series and parallel.' — Mixed team, Group C

> '. . .it helped me understand pump head and other relevant applications' — Positive team, Group D

> 'I saw how the placement of pumps in series and parallel increased the total head. I also understood the concept of head better as I was confused about that in class.' — Mixed team, Group D

These expressions of abstraction are strong indicators of what Maton (2009) calls cumulative learning, and are key indicators for the students' cognitive linkage between practice and theory. It is this linkage that is so often missing from practical courses, noted by Louw (2016). In contrast to the expressions of motivation and enjoyment, and demonstrations of learning quoted above, when questioned about the regular practical course students expressed disinterest, and difficulty in learning:

> '[I prefered t]his pumping practical. I did not understand most of my [usual practical module] practicals, as the theory was not covered before. Therefore the practical confused me rather than improve my understanding'. — Positive team, Group A

> '[The usual practical module] felt like turning valves and crunching numbers.' — Mixed team, Group C

> 'We had to figure it [this intervention practical] out by ourselves. It wasn't just a "set-up"; we had to set up the experiment ourselves. If we did not do it right, it did not work. So we could learn from our mistakes. The. . . [usual practical module] pracs were boring.' — Negative team, Group D

On the other hand, there were several students who responded that they did learn during the write-up of the usual practical module's practical reports. It is clear that not everyone learns or is motivated in the same way, and the usual methodology does indeed generate understanding in students.

One limitation of this study, which the authors will work to investigate in further work, is that there is no reliable quantified measure of students' understanding (i) pre- and post-practical and (ii) on a longer-term basis, as a result of this practical. So, while students do demonstrate their learning both during the practical, noted by the facilitator, and in their responses the exit questionnaire, this cannot be considered to be conclusive. Further proposed studies hope to elucidate this.

5. Conclusions

The practical intervention outlined in this study was designed to be a non-assessment driven, informal, competitive practical, to stimulate the linkage between the theoretical and practical, within a fluid mechanics module. The results indicate that not only did the practical achieve the aim of forging cumulative learning through the open-ended application of theory to practice, but additionally the environment and context of the practical decreased students' perceptions of time pressure, workload and anxiety. This is a significant outcome in a module which has historically been viewed as 'difficult', exacerbating student anxiety, and historically known by the faculty to be a bottleneck module within the programme.

There is no doubt that when the course content lends itself to having material manifestation, students benefit from the experience of performing a practical which challenges and extends their knowledge. However, there is a significant pitfall which university educators often fall foul of: that is, to facilitate practicals where there is little scope for student engagement, beyond simple measurement-taking. Further, the use of assessment, while often valuable in driving learning, can also lead to students' by-passing 'deep' learning in favour of 'surface' or 'strategic' learning, particularly in a practical context.

It was noted during this intervention that the logistical and implementation context (i.e. low pressure, non-assessment driven, informal and competitive) made a significant contribution to both student engagement and learning. These factors seemed to facilitate students' exploration of the links between theory (the mathematics describing the systems) and the practical—these linkages are paramount in developing a full and mature knowledge base.

While significant literature and experience does suggest that assessment drives and forces learning, the authors would like to add another layer to this notion, by suggesting that non-assessment driven learning can also be forged. In this case study, peer interactions, proximity to other groups and competitive elements contributed to forms of learning that not only enabled epistemic access, but also the very attributes required by the field (i.e. leadership, teamwork, problem-solving, and ethics). And while this methodology for driving learning may not be applicable in all cases and all practicals, the authors would like to suggest that it does have a place within university education.

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Appendix A. Entry questionnaire

1. Are you at all anxious or worried about this course?

☐ Very anxious ☐ A little anxious ☐ Relaxed ☐ Very confident

If you are feeling at all worried about the course, what are you worried about? (e.g. you've heard the course is difficult, the lecturer has a reputation for being strict, you're worried about time constraints etc.)

2. From what you have heard of this course, how difficult do you expect it to be overall?

☐ Very difficult ☐ A little difficult ☐ Manageable ☐ Easy

3. From what you have heard of the second year of chemical engineering, how much time pressure do you expect to be under?

☐ Very time constrained ☐ A little time constrained ☐ Manageable ☐ Lots of free time

4. From what you have heard of the course, how challenging to you expect the tutorials and assignments to be?

☐ Very difficult ☐ A little difficult ☐ Manageable ☐ Easy

5. How motivated are you feeling for this course?

☐ Unmotivated ☐ Apathetic ☐ A little motivated ☐ Very motivated

6. Is this your first time registered for CE264?

☐ First time ☐ Registered before

7. How much hands-on experience have you had with fluid-flow equipment? (e.g. valves, pumps, pipe fittings such as bends and joins, pipes of various diameters, flow meters etc.)

☐ None ☐ Very little ☐ Some experience ☐ Significant experience

8. How much do you know about the following content in the theory of fluid mechanics

Flow characteristics (laminar or turbulent flow)	☐ None	☐ Some experience	☐ Significant experience
Flow energy (flowrates, pressure)	☐ None	☐ Some experience	☐ Significant experience
Flow characteristics in pipes (pressure losses, velocity profiles)	☐ None	☐ Some experience	☐ Significant experience
Pump characteristics (flowrate vs pressure, efficiency curves)	☐ None	☐ Some experience	☐ Significant experience
Pump selection (efficiency, selection for piping networks)	☐ None	☐ Some experience	☐ Significant experience

Comments:

Appendix B. Exit questionnaire

1. Now that you have completed the course, are you at all anxious or worried about the final outcome of this course?

☐ Very anxious ☐ A little anxious ☐ Relaxed ☐ Very confident

If you are feeling at all worried or anxious about the final outcome, could you describe why you are feeling this way?

2. Now that you have completed the course, how difficult did you experience it to be overall?

☐ Very difficult ☐ A little difficult ☐ Manageable ☐ Easy

3. Thinking specifically about this course, how time constrained were you?

☐ Very time constrained ☐ A little time constrained ☐ Manageable ☐ Lots of free time

4. After completing the course, how positive are you feeling about the course in general?

☐ Very negative ☐ Apathetic ☐ A little motivated ☐ Very motivated

5. Thinking back to the pumping practical that you did for this course, could you explain your experience of the practical session?

6. Thinking back to the pumping practical, would you say the practical helped your general understanding of some of the concepts of fluid mechanics? Could you specifically say how/what it helped you understand, if anything?

7. Which order of doing do you think will be better for your understanding of the subject matter: first doing a practical and then writing a test about it, or first writing a test and then applying the theory in a practical?

8. Are there any other comments about the practical session that you would like to add?

References

Abdel-Salam, T., Kauffman, P.J., Crossman, G., 2006. Does the lack of hands-on experience in a remotely delivered laboratory course affect student learning? Eur. J. Eng. Educ. 31, 747–756, http://dx.doi.org/10.1080/03043790600911886.

Barnett, M., 2006. Vocational knowledge and vocational pedagogy. In: Young, M., Gamble, J. (Eds.), Knowledge, Curriculum and Qualifications for South African Further Education. HSRC Press, Cape Town.

Becher, T., Parry, S., 2005. The endurance of the disciplines. In: Bleiklie, I., Henkel, M. (Eds.), Governing Knowledge. Springer-Verlag, Berlin/Heidelberg, pp. 133–144, http://dx.doi.org/10.1007/1-4020-3504-7_9.

Brown, P.R., McCord, R.E., Matusovich, H.M., Kajfez, R.L., 2015. The use of motivation theory in engineering education research: a systematic review of literature. Eur. J. Eng. Educ. 40, 186–205, http://dx.doi.org/10.1080/03043797.2014.941339.

Chen, W., Shah, U., Brechtelsbauer, C., 2016. The discovery laboratory—a student-centred experiential learning practical: part I—overview. Educ. Chem. Eng. 17, 44–53, http://dx.doi.org/10.1016/j.ece.2016.07.005.

Chin, C., Brown, D.E., 2000. Learning in science: a comparison of deep and surface approaches. J. Res. Sci. Teach. 37, 109–138, http://dx.doi.org/10.1002/(SICI)1098-2736(200002)37:2<109:AID-TEA3>3.0.CO;2-7.

Council for Higher Education, S.A, 2013. A Proposal for Undergraduate Curriculum Reform in South Africa: The Case for a Flexible Curriculum Structure. Council on Higher Education, Pretoria.

Delgado, M.A., Fonseca-Mora, M.C., 2010. The use of co-operative work and rubrics to develop competences. Educ. Chem. Eng. 5, e33–e39, http://dx.doi.org/10.1016/j.ece.2010.05.002.

Depaolo, C., Mclaren, C.H., 2006. The relationship between attitudes and performance in business calculus. INFORMS Trans. Educ. 6, 8–22, http://dx.doi.org/10.1287/ited.6.2.8.

Entwistle, N., 2000. Promoting deep learning through teaching and assessment: conceptual frameworks and educational contexts. In: The TLRP Conference, Leicester.

Fadali, M.S., Velasquez-Bryant, N., Robinson, M., 2004. Work in progress—is attitude toward mathematics a major obstacle to

engineering education? 34th Annual Frontiers in Education, 2004. FIE 2004. IEEE, 573–578, http://dx.doi.org/10.1109/FIE.2004.1408582.
Ferreira, A., Santoso, A., 2008. Do students' perceptions matter? A study of the effect of students' perceptions on academic performance. Account. Finance 48, 209–231, http://dx.doi.org/10.1111/j.1467-629X.2007.00239.x.
Funke, J., Frensch, P., 1995. Complex problem solving research in North America and Europe: an integrative review. Foreign Psychol. 5, 42–47.
Griesel, H., Parker, B., 2009. Graduate Attributes: A Baseline Study on South African Graduates from the Perspective of Employers. Higher Education South Africa & the South African Qualifications Authority.
Gynnild, V., Myrhaug, D., Pettersen, B., 2007. Introducing innovative approaches to learning in fluid mechanics: a case study. Eur. J. Eng. Educ. 32, 503–516, http://dx.doi.org/10.1080/03043790701433137.
Jones, B.D., Paretti, M.C., Hein, S.F., Knott, T.W., 2010. An analysis of motivation constructs with first-year engineering students: relationships among expectancies, values, achievement, and career plans. J. Eng. Educ. 99, 319–336, http://dx.doi.org/10.1002/j.2168-9830.2010. tb01066.x.
Kolb, D., 2014. Experiential Learning: Experience as the Source of Learning and Development, 2nd ed. Pearson Education.
Lefebvre, B.G., Connell, L.E., Dahm, K.D., 2009. Competition between student groups in the protein production challenge. Educ. Chem. Eng. 4, e1–e8, http://dx.doi.org/10.1016/j.ece.2008.11.001.
Louw, T., 2016. Instant data processing for active reflection in engineering laboratory practicals. In: The Ninth Annual Stellenbosch University Conference on the Scholarship of Teaching and Learning, Stellenbosch.
Maton, K., 2013. Making semantic waves: a key to cumulative knowledge-building. Linguist. Educ. 24, 8–22, http://dx.doi.org/10.1016/j.linged.2012.11.005.
Maton, K., 2009. Cumulative and segmented learning: exploring the role of curriculum structures in knowledge building. Br. J. Sociol. Educ. 30, 43–57, http://dx.doi.org/10.1080/01425690802514342.
Muller, J., 2009. Forms of knowledge and curriculum coherence. J. Educ. Work 22, 205–226, http://dx.doi.org/10.1080/13639080902957905.
Najdanovic-Visak, V., 2017. Team-based learning for first year engineering students. Educ. Chem. Eng. 18, 26–34, http://dx.doi.org/10.1016/j.ece.2016.09.001.
Ram, P., 1999. Problem-based learning in undergraduate instruction. A sophomore chemistry laboratory. J. Chem. Educ. 76, 1122, http://dx.doi.org/10.1021/ed076p1122.
Rooch, A., Junker, P., Härterich, J., Hackl, K., 2016. Linking mathematics with engineering applications at an early stage—implementation, experimental set-up and evaluation of a pilot project. Eur. J. Eng. Educ. 41, 172–191, http://dx.doi.org/10.1080/03043797.2015.1056095.
Savage, N., Birch, R., Noussi, E., 2011. Motivation of engineering students in higher education. Eng. Educ. 6, 39–46, http://dx.doi.org/10.11120/ened.2011.06020039.
UNESCO, 2010. Engineering: Issues, Challenges and Opportunities for Development. Paris, United Nations Educational, Scientific and Cultural Organization.
Young, B.R., Yarranton, H.W., Bellehumeur, C.T., Svrcek, W.Y., 2006. An experimental design approach to chemical engineering unit operations laboratories. Educ. Chem. Eng. 1, 16–22, http://dx.doi.org/10.1205/ece.05005.
Zou, T.X.P., Ko, E.I., 2012. Teamwork development across the curriculum for chemical engineering students in Hong Kong: processes, outcomes and lessons learned. Educ. Chem. Eng. 7, e105–e117, http://dx.doi.org/10.1016/j.ece.2012.04.003.