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Benchmarking educational quality – an analysis and alternative practical learning theory and technology

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In a ten-year study over thirty STEM units in seven nationally accredited institutions (two colleges, five universities, including a five-star teaching university) in two different countries were analyzed to evaluate their educational quality using a range of criteria and benchmarked against the finalists of the 2010 IEEE global award for academics. Unit content and teaching were found to be almost exclusively based on Constructivist based principles. However, Constructivism provides subjective guidelines open to different interpretations. The analyzed units demonstrated considerable variation in pass rates and educational standards. One unit consistently achieved circa 100% pass rates but at the expense of the standard of learning outcomes – far below any reasonable expectations. At the other extreme one unit achieved a higher standard of learning but with pass rates below 30%. This problem can potentially be addressed by using the new quantitative Cognitive Load Optimization learning theory and technology.

Keywords: academic quality, Science of Learning, Cognitive Load Optimization

Benchmarking teaching and learning quality – is it value for money?

National accreditation provides a regulatory quality assurance framework for all aspects of further and higher education. Within Australia the Tertiary Education Quality and Standards Agency (TEQSA) employs the Higher Education Standards Framework (HESF) which consists of seven domains (Agency, 2017) which variously serve to ensure academic quality standards i.e. a desired level of quality of an academic activity has been attained. Undergraduate full cost annual tuition fees are between A$15,000 to over A$30,000. An undergraduate bachelor's degree represents a significant financial investment with not unreasonable expectations of a high-quality learning standard and experience.

The Structure of the Observed Learning Outcomes (SOLO) education taxonomy was used in this study which, excluding pre-structural, has four levels (Biggs, Collis, 1982).

- Unistructural (level 1): learner focuses on only one relevant aspect. Assessed by verbs such as identify, name.
- Multi-structural (level 2): learner focuses on several relevant aspects. Assessed by verbs such as describe, enumerate, list.
- Relational knowledge (level 3): learner has an integrated, coherent structure thereby allowing a student to explain how something works and also answer complex problems. Assessed by verbs such as explain, justify.
- Extended abstract (level 4): learning employs relational knowledge to a higher level of abstraction and hence can generalize to another topic. Assessed by SOLO verbs such as reflect, theorize, explain.

The first two levels are low order, rote learning. The objective teaching is high order learning resident in long term memory i.e., SOLO levels 3 and 4. According to Halford, 'Arguably relational knowledge represents the core of higher cognition' (Halford, 2010). Over thirty STEM units in seven institutions (two college, five universities – including a five-star teaching university) in Australia and Thailand were analysed. Topic disciplines included: project management, electrical principles, cybersecurity (introductory and advanced), Programming (introductory and advanced), Information Technology, network technology (introductory and advanced), mathematics, medical informatics etc. This study included STEM based units on Business study courses. The units were evaluated according to criteria that included:

- Content scope and depth
- Learning outcomes i.e., in the final exam, ranked based on SOLO assessment verbs
- Pass and attrition rates
- Scaffolding i.e., for units with pre-requisites evidence of previously acquired relational knowledge in long term memory

The units were also benchmarked against the finalists for the 2010 IEEE global award for academics. The IEEE is the world's largest technical professional organization dedicated to advancing technology for the benefit of humanity. The results of a representative sample of units are as follows.

Project Management – college and university undergraduate

The same topic, project management, was offered by two institutions (Table 1).

Table 1. Project management

Project Management	Pedagogical approach	Delivery mode	Attrition rate	Pass rate	SOLO level
Institute 1 College, Diploma	Constructivism, student centric, self-paced learning	Face-to-face	Low	Circa 100%	Theory - 2 Practical - 3
Institute 2 University, Undergraduate	Constructivism, lecturer centric	Face-to-face	Low	Circa 100%	Theory – 2 Practical - 3

Institute 1 observations:

- Unit description, 'Informed by modern commercial practices and based on the best educational practices.'
- No pre-requisite units
- Student contact time: two 3-hour sessions per week
- The pedagogical approach was substantially Constructivism, student centric, self-paced learning
- Content scope and depth. Instructional materials provided were scant. For example, the material provided for weeks 2, 3, 5, 7 and 8 had less than ten power point slides each week. Many even basic topics not taught such as dependency types etc. Students were required to interpret a project implemented in a project management tool
- Final exam was predominantly SOLO level 2. However, the ongoing practical assessment had aspects of SOLO level 3.
- Quality assurance was a counter signed seven-page checklist of generic statements e.g., numeracy and documentation skills to develop cost-benefit analyses

Institute 2 observations

- Unit description, 'An outstanding and award-winning unit.'
- No pre-requisite units
- The pedagogical approach was Constructivism, lecturer centric i.e., twelve, 90-minute lectures
- Unit content scope and depth. As an undergraduate unit more basic topics were taught, however more difficult and complex topics such Earned Value Management (EVM), Program Evaluation and Review Technique (PERT) were not taught.
- Like some other institutes spreadsheets were used to teach this subject. Project management is the dynamic interaction between scheduling, constraints, costs etc., that can only sensibly be taught by a project management tool which are freely available.
- Final exam was open book exam based on multiple choice questions, very simple calculations and short questions i.e., SOLO level 2. The practical assessment could be considered SOLO level 3. To benchmark the pedagogical level of the exam, the unit materials (lecture power points and textbook) were given to a schoolboy (14 years old) and with no preparation time was asked to attempt the final exam within a 3-hour time limit. The child passed the exam with a distinction.

Network technology – university undergraduate

At one institute the unit Network Technology 1 was the pre-requisite to Network Technology 2 i.e., dependence on previously acquired relational knowledge resident in long term memory (scaffolding). A cohort of 33 students who had just successfully completed the first unit and attending the second unit were asked ten questions to evaluate their knowledge of basic, fundamental networking concepts. For example, what does ARP stand for, why is it needed and how does it work? What is the difference between a frame and a packet? How does a router work? All students scored zero. In the Network Technology 2 unit the instructional materials provided were primarily technical manuals with some supporting materials. The pedagogical approach was to make the students responsible for 'learning how to learn' placing the emphasis of learning complex knowledge onto the students.

Introduction to programming – university, undergraduate

The same topic, introduction to programming, was taught by the same institution in three geographically remote locations by three different lecturers all using the same material (Table 2).

Table 2. Introduction to programming

Introduction to programming -undergraduate	Pedagogical approach	Delivery mode	Attrition rate	Pass rate	SOLO level
Site 1	Constructivism, lecturer centric	Face-to-face	Low	<30%	3
Site 2	Constructivism, lecturer centric	Face-to-face	Low	<30%	3
Site 3	Constructivism, lecturer centric	Face-to-face	Low	<30%	3

Observations:

- No pre-requisite units
- Content scope and depth. Extensive materials covering all the major concepts.
- Final exam SOLO level 3
- The same material was used at three geographically located sites by different lecturer with low pass rates

The materials for this unit were extensive and covered all the major concepts of Programming. However, all these concepts represent complex relational knowledge which is hard to teach and learn. The same material was used by three different lecturers on three geographically remote sites but pass rates at all sites was less than 30%. A seemingly persistent pass rate. This was considered acceptable as, 'Students do not apply themselves sufficiently'. The students considered this to be a very tough unit.

Mathematics – university undergraduate

First year undergraduate mathematics is an essential unit for all engineering courses. The unit in one institute included all topics expected however it was also taught in remote on-line mode to students in many different countries including developing countries with unreliable and low bandwidth internet access. To help students pre-recorded lectures were available. However, the problems associated with synchronous mode deliver were considerable. Lectures had to be based on the lowest bandwidth thereby excluding video. All communication was voice and text-based chat. It was very difficult for students to type equations in the chat line. It was not uncommon for students to have technical problems e.g., unable to logon and line drop-off who then required further assistance which was only available by email. Explaining complex mathematically problems asynchronously is challenging compounded by students being resident in different time zones. Attrition rates were consistently high along with low pass rates and student complaints about the teaching quality. The engineering mathematics unit in another institute was offered in face-to-face mode however, even though this was a first-year unit it did not teach any topics one would expect e.g., differential calculus, integral calculus, Laplace transforms, etc. The material was primarily a 'pure' mathematics unit consisting of mathematical proofs with only one practical example – a chemical reaction. Further studies would be needed to investigate the effectiveness of this approach, but it was difficult to see how this supported learning in other concurrent engineering topics that needed complex mathematic fluency.

STEM units for Business studies – university undergraduate

A business degree may require students to study units in STEM technical subjects such as IT infrastructure, cybersecurity etc. These are technically complex subjects; however, business students typically do not have a technical background, Five STEM based business units offered by two universities were analysed. All of these units delegated quality to prescribed textbooks – arguably a cost-effective approach. Two units were entirely based on textbooks that taught lists of technologies with either limited or no explanations. For example, '*NAT filtering is a type of firewall filtering network traffic based on TCP/UDP ports.*' The acronyms were often not explained and sometimes not even defined. Neither of these units provided supplementary materials to address this problem. Three units were textbook based but provided extensive supplementary material and reading lists. However, the end result was the same – students were taught lists of technologies with either limited or no explanations. One unit had numerous technical explanations that were incorrect and discussed the use of technologies that have been obsolete for decades e.g., token ring, floppy disc drives for backup etc. For three of these units the learning outcomes of 64 students (unit 1: 29 students; unit 2: 12 students; unit 3: 23 students) who had successful passed these units, was evaluated. Students were given full access to the unit materials and given questions designed to assess relational knowledge such as: 'In simple terms how does a router work? What does a hash function do and why is it used? All 64 students scored zero. This would suggest their learning was low order rote learning i.e., learning without understanding. The object is not to make them technical experts – which is not desirable or possible. Rather the objective should be to provide technical literacy to support their future management roles.

Summary

An undergraduate award represents a significant financial investment. Accreditation is designed to ensure academic quality standards. However, in the units analysed, claims of quality learning were often difficult to substantiate. One unit had material that not only had significant technically errors but also included obsolete technologies. Teaching lists of technologies, with little or no explanation, was common. High pass rates are not an assurance of quality learning outcomes as they were sometimes achieved by teaching and assessing at a low standard. One unit taught to a higher standard, but the acceptance of low pass rates placed the onus of learning on the student rather than asking how the teacher can achieve better results. Because educational standards were self-defined, staff generally considered there was little or no scope for improvement and hence were sensitive to and seemingly intolerant of benchmarked constructive critical comments. The problem is how to teach complex relational knowledge, assessed at SOLO level 3 or above and achieve high pass and retention rates.

Cognitive Load Optimization – a new practical 21st Century alternative educational theory and technology

There are a range of learning theories in use today such as Constructivism, Behaviourism, Cognitive Psychology with associated techniques and methods. For the unit's analysed teaching was based on Constructivist principles in which students are guided to construct their own mental schema (mental pattern of knowledge). However, these 20th century learning theories are based on subjective, soft science principles. Hence, they are open to different interpretations with implications for quality learning outcomes that, as found in this paper, can result in subjective, self-defined standards. The term 'soft' is not pejorative as humans are complex systems not readily tenable to quantitative hard scientific methods. The Science of Learning (SoL) research agenda defined the goal of optimised learning for all (NSF, 2013, 2017). The Australian Science of Learning Research Centre (SLRC) developed twelve subjective Psychology, Education and Neuroscience (PEN) principles, but no quantitative hard science-based method (Centre, 2020). Optimization is only possible if learning is based on a quantitatively based learning theory.

In Cognitive Load Theory (CLT) knowledge is measured by Intrinsic Cognitive Load (ICL) (Sweller, 1998). Complex relational knowledge, the goal of quality learning outcomes, has a high ICL and is therefore difficult to teach and learn as all learning is mediated by short term memory which has limited capacity and duration and therefore easily overloaded – hence the low pass rates reported in this study. However, in CLT there is no direct measurement of cognitive load only an induced result (de Jong, 2010). Cognitive Load Optimization (CLO) is a new, practical 21st Century learning theory and technology that uses a simple, quantitative, hard science based method for measuring ICL. Hence using CLO, it is possible to reduce the ICL of material to be taught thereby creating the simplest possible schema that represents the provable easiest learning path. The optimized schema is the basis of instructional development and teaching. Importantly, unlike Constructivism and other 20th century learning theories and methods, the CLO quantitatively optimised schema is given to the students. CLO is not only a learning theory but also an educational technology/tool – optimisation can be done by software or manually. CLO has been extensively evaluated and results in significantly improved learning outcomes even in the more challenging online mode (Maj, 2018, 2020; Maj, Nuangjamnong, 2020; Nuangjamnong, 2022). The efficacy of eLearning tools/technologies has been questioned (Holkner, 2008). CLO derived eLearning tools/technologies result in significant improvements in learning outcomes achieved in considerably less time (Maj, Kohli, & Murphy, 2004; Maj, Kohli, & Fetherston, 2005; Maj, Veal, 2007).

Conclusions

Despite accreditation there was a wide range of pass rates and educational standards in the units analysed. High pass rates (circa 100%) were sometimes achieved by teaching and assessing low order multi-structural knowledge. In numerous units it was difficult to substantiate claims of high-quality learning. For units with higher learning standards the pass rates, in one case, were less than 30%. The goal of learning is students acquiring complex relational knowledge. However, relational knowledge is difficult to both teach and learn. The educational theories in use today are based on subjective soft science-based guidelines that can be differently interpreted potentially resulting in wide variations in learning outcomes as evident in this paper. By contrast the CLO method is a quantitative hard science learning theory that creates the provable simplest schema with the optimised minimum cognitive load. Unit material development and teaching based on this schema represent the easiest learning path. Unlike Constructivism and other 20th century learning theories and methods, the optimised schema is given to the students. All work to-date demonstrates that by using CLO it is possible to address the problem of teaching complex relational knowledge whilst still achieving high pass and retention rates but without compromising educational quality. CLO works for all STEM disciplines at different educational levels. Preliminary investigations strongly suggest CLO is theoretically applicable to other disciplines; however further work is needed.

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