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Sharon Nightingale
University of Wollongong, sharon@uow.edu.au

Anna L. Carew
University of Wollongong, carew@uow.edu.au

Justin Fung
University of Wollongong

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Application of Constructive Alignment Principles to Engineering Education: Have we really changed?

Sharon Nightingale
University of Wollongong, Wollongong, Australia
sharon_nightingale@uow.edu.au

Anna Carew
University of Wollongong, Wollongong, Australia
Email address

Justin Fung
University of Wollongong, Wollongong, Australia

Abstract: *A survey of some common engineering subjects in four Australian universities shows that despite much discussion of student-centred learning, assessment is still very heavily based on examinations. Analysis of exam questions, and other assessment tasks, using the Revised Bloom's Taxonomy, also shows that in some cases there may be significant mismatch between the stated learning objectives of subjects and the way in which students are assessed. Application of constructive alignment to design of assessment has the potential to ensure that assessment tasks reflect the learning objectives, and may help encourage academics to consider alternatives to examinations.*

Introduction

Student-centred learning and assessment

In engineering courses around the world, there has been a traditional reliance on exams as the only robust way to test individual engineering students' knowledge. However, professional societies such as Engineers Australia and employers increasingly expect graduate engineers to have a broad range of generic skills, such as creativity, communications skills and the ability to work in teams, as well as technical expertise in their particular field. Formal examinations usually involve answering a limited number of structured questions in a high pressure environment, and as such have limited ability to test these broader skills. As Lewis Elton (2004) points out, the value of examinations as a reliable assessment of student learning has been in question since the 1930's, yet there has been little change. The idea of learning being student-centred challenges our reliance on exams

How is assessment linked to quality of learning?

John Biggs (1999) describes university assessment as 'backwash'. Of all of the possible signals that university students might pick up on, nothing is more pervasive or effective in shaping how students respond to tuition than assessment. As Prof Gary Poole from the University of British Colombia suggests, one minute spent examining the assessment regime of any given university course is a quick and remarkably accurate way to predict how students will be allocating their time in studying (G. Poole, pers comm.). The powerful and pervasive influence of assessment on university students has been well researched and documented (reviewed in Prosser and Trigwell, 1999), and a growing number of engineering education researchers are exploring and documenting the strength of the association (Oehlers and Walker, 2006; Roselli et al, 2006; Spector, 2006).

The significance of the link between assessment and approach to study is that the approach students take will strongly influence the *quality* of learning they achieve. In broad terms, students can choose to take a *surface* or *deep* approach to their learning (Prosser and Trigwell, 1999). Students who take a surface approach typically have the intention of memorising large quantities of factual information in order to pass an exam. In contrast, students who take a deep approach tend to learn for understanding. These deep learners have been documented to achieve richer comprehension and greater long term recall. While there is a place for some surface learning in engineering such as basic definitions of stress and strain, a deep approach to study allows students to make strong conceptual connections between new knowledge and their existing knowledge, and relate new knowledge to their existing understanding of the calling or profession they aspire to enter (eg engineering).

Classifying learning objectives and assessment tasks

An effective and longstanding way of describing the quality of learning that academics might aim to teach, or that students might work to achieve is Bloom's Taxonomy (Bloom et al, 1956). Bloom's Taxonomy allows us to refine the broad categorisation of learning as deep or surface. Further, the research we will present in this paper rests, in part, on Bloom's Taxonomy and so we will describe it in some detail. The Taxonomy provides six levels for classifying cognitive process, and we have explained these six with reference to examples from the domain of engineering (Table 1).

Table 1: Bloom's Taxonomy for Engineering (adapted from Goel & Sharda, 2004 and Van Wie, 2006)

	Definition	Typical Action Verbs
1. Knowledge	memorisation of facts, definitions, recall of methods and procedures	identify, define, show, state, obtain
2. Comprehension	ability to convey knowledge in alternative ways, interpretation of knowledge	compare, describe, explain, discuss, classify
3. Application	apply and transfer knowledge to different contexts, use abstract ideas in real situations	apply, calculate, determine, estimate, show, find, solve
4. Analysis	ability to break down a complex problem into parts, solve each part, determine connections between parts	analyse, contrast, examine, justify, predict, test, deduce
5. Synthesis	assembling parts to create a new whole, integration of application knowledge with other skills, solves open ended problems	construct, design, create develop, produce, devise, integrate
6. Evaluation	ability to evaluate or judge design, solution to problem, presentation	argue, assess, evaluate, judge, validate, review

Bloom's taxonomy represents a hierarchical structure of learning that presumes the higher levels of learning were achieved only after the less complex skills were mastered. Application of the Taxonomy over the years revealed some weaknesses in the one dimensional structure. By combining both the noun and the verb in a single definition of "Knowledge", there was a lack of ability to distinguish between types of knowledge, and what the student was meant to do with it. The cumulative nature of the taxonomy limited its flexibility, and the sequencing of classifications in terms of complexity did not always work when applied to classification of learning objectives and tasks (Krathwohl, 2002, Ormell, 1974). There was a need for a revised taxonomy.

Such a taxonomy was devised by Anderson and others (2001) (see Table 2) and this revised taxonomy added a second dimension to Bloom's Taxonomy, thereby allowing the type of knowledge being learned to be recognised and categorised. Bloom's first dimension was dubbed the *cognitive process dimension* and the second dimension was called the *knowledge dimension*. The knowledge dimension encompassed four categories:

1. Factual knowledge: basic terminology, symbols, constants, sources of information
2. Conceptual knowledge: classifications, principles, theories, models, structures

3. Procedural knowledge: "how to do something", algorithms, methods, techniques and criteria used to select appropriate methods
4. Metacognitive knowledge: awareness of learning and learning strategies, techniques to improve learning, knowledge of one's own abilities and weaknesses, ability to recognise higher and lower level thinking

Table 2: Revised Bloom's Taxonomy (Anderson and Krathwohl, 2001)

The Knowledge Dimension	The Cognitive Process Dimension					
	1. Remember	2. Understand	3. Apply	4. Analyse	5. Evaluate	6. Create
A) Factual Knowledge						
B) Conceptual Knowledge						
C) Procedural Knowledge						
D) Metacognitive Knowledge						

As we will demonstrate in this paper, the Revised Taxonomy is a profoundly useful tool for reviewing and reflecting on the stated objectives, teaching and learning activities and assessment tasks that constitute a subject or course at university. In the following sections we discuss the principle of constructive alignment, and explain in theoretical terms how the Revised Taxonomy can be used to 'check' the alignment between these three things.

Constructive alignment and the Revised Taxonomy

Constructive alignment is a concept created by John Biggs as a tool for checking and ensuring that the learning objectives of a subject accurately align with both the delivery (teaching and learning activities) and the assessment regime (Biggs, 1999). There are two key concepts that underpin constructive alignment:

1. learning comes from the students as they work to gain meaning from activities, and
2. effective teaching is teaching that targets the learning outcomes through supported and related activities (teaching, learning and assessment activities).

Achievement of learning objectives requires students to engage in a range of activities (e.g. tutorials, laboratories, design projects, exams), and it is the teacher's task to get students to engage with these activities. One way of encouraging this is to clearly explain the desired learning objectives to the students so that they know what is expected and can take some responsibility for their learning. Another key way to encourage engagement is to design the assessment methods to match the stated learning objectives, as most students will strongly tailor their learning to suit the structure of the assessments and gain maximum marks. If the assessment tasks do not match the objectives, students can start to lose trust in the teacher and the system, and may revert to strategic surface learning. Constructive alignment is then about giving clear and consistent signals about what is important to learn (knowledge dimension) and how it should be understood (cognitive process dimension), and about. These strong signals need to be explicit and consistent in the subject documentation (eg. learning outcomes) and in all subject activities (teaching, learning and assessment). The pay off of constructive alignment for the teacher is higher likelihood students will learn in the desired way, development of trust and shared purpose between teacher and student, and growing students' confidence in their own learning (Engineering Subject Centre, 2007).

Aims

This paper describes research completed in 2007 as part of a fourth year honours project in the School of Civil, Mining and Environmental Engineering at the University of Wollongong (UoW). The student researcher was Mr Justin Fung and his research was co-supervised by Associate Professor Sharon Nightingale (School of Mechanical, Mechatronics and Materials Engineering, UoW) and Dr Anna Carew (Centre for Educational Development and Interactive Resources, UoW).

The aims of the research reported here were to:

1. Generate an overview of 'typical' assessment regimes in Civil Engineering by auditing the assessment practices in Civil Engineering at three Australian universities by quantifying the percentage of overall assessment marks allocated by three different classes of assessment method (exams, assignments, laboratory practicals);
2. Examine and quantify the type of cognitive processes required to answer exam questions in Civil Engineering at the three universities; and
3. Compare the cognitive processes and the knowledge dimension specified in subject learning outcomes with the cognitive processes and the knowledge dimensions examined by a subject's assessment regime.

Methods and Results

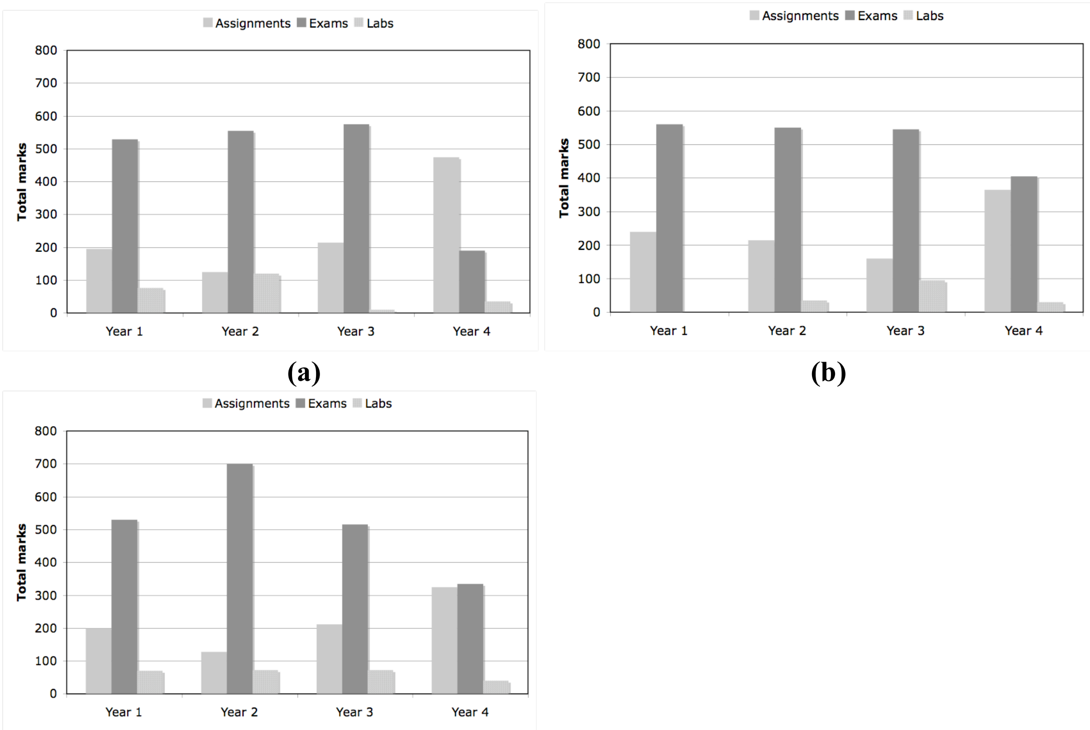
'Typical' assessment regimes in Civil Engineering & Assessment marks by assessment method

Subject outlines for all subjects from each of the four years of the Civil Engineering course were obtained from UoW, University of Queensland (UQ) and University of Melbourne (UMelb). The percentage of the total assessment for each assessment task in a subject was noted. Midterm exams, quizzes and final exams were grouped together under "exams". Laboratories, practicals and field trips were classified as labs, and various types of assignments and "class participation" were grouped as "assignments". In the fourth year, a thesis or major project has been included with "assignments" apart from any associated exam. The University of Adelaide and University of Sydney Civil degrees were also targeted but only some subject outlines were available, so they were not included in this analysis. Results are shown in Figure 1.

Cognitive processes required to answer exam questions

Given the high universal reliance on exams across all four years of study that was observed in all of the Civil courses, we decided to analyse the cognitive processes required of students sitting exams in selected subjects. We obtained final exam papers from two core civil engineering subjects in each year of the course, giving a total of eight exam papers from each university for analysis. Unfortunately, UQ exam papers were only available to students and staff, so they were excluded from this part of the analysis.

Each exam question was then analysed by the Honours student (Mr J Fung) using a slightly simplified version of the modified taxonomy shown in Table 2. The six cognitive process dimensions were collapsed into three levels (Remember and Understand = Level 1, Apply and Analyse = Level 2, and Evaluate and Create = Level 3). This was done to allow for frequent overlap that was found across these categories in many questions, and to simplify the analysis. Results are shown in Figure 2.



(a) (b) (c)

Figure 1: Total marks ascribed to different types of assessment in each year of a Civil Engineering course. (a) UoW (b)UMelb (c)UQ

Revised Bloom's Taxonomy – learning objectives and assessment

Having observed very little consistency (within subject or between years) in the cognitive processes required to answer the exam questions analysed, we wondered if the cognitive processes required in exams tended to align with those that were indicated by a subjects' stated learning objectives. We also wondered if different cognitive processes might be required by other parts of a subject's assessment regime. To investigate this, three subjects from different universities were selected for detailed analysis of stated learning objectives and assessment tasks. The subjects were all core civil engineering subjects. Subjects which incorporated different types of learning activities were chosen (e.g. tutorial hand-ins, assignments, quizzes, field trips, labs, etc.) to see whether the different activities would be reflected in the types of cognitive processes assessed. Subject choice was limited by the availability of the teaching materials to the Honours student (Mr J Fung). Subject outlines were obtained from web sites or directly from lecturers. Assessment materials were obtained from libraries, faculties or lecturers.

Each subject's learning objectives were scrutinized and divided into a noun and verb phrase, and then classified according to the Revised Bloom's Taxonomy shown in Table 2. For each assessment task, every question was also analysed in terms of the type(s) of knowledge required and cognitive processes involved in answering the question, including, where appropriate, the ability to analyse a question and choose the most appropriate methods for answering it. It should be noted that it is possible for one question to address more than one objective, and this is shown where applicable. The results of this analysis were entered into the same table as the learning objectives analysis, and the alignment between the two was checked. Results are shown in Tables 3 to 5.

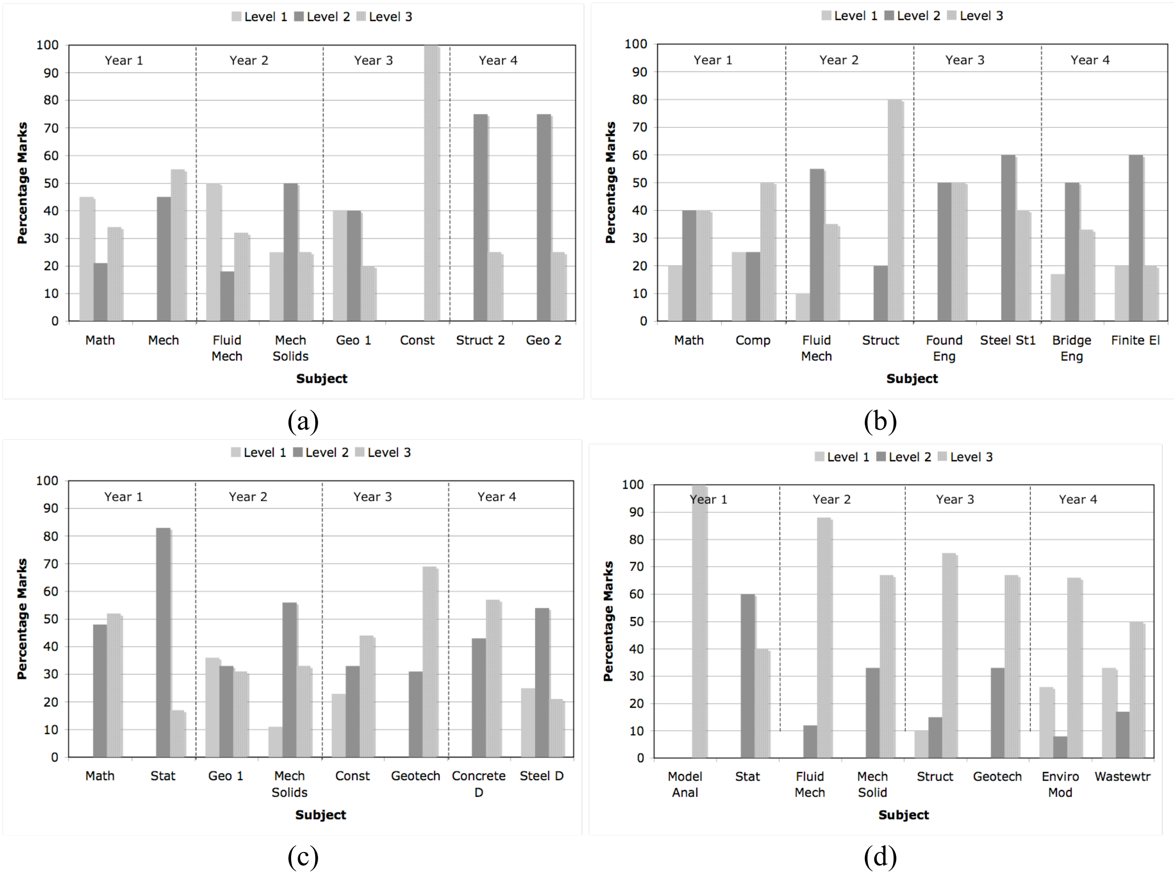


Figure 2: Level of cognitive processes associated with answering exam questions in civil engineering courses at four universities. (a) University of Wollongong (b) University of Sydney (c) University of Melbourne (d) University of Adelaide

Table 3: Analysis of Learning Objectives and Assessment Tasks for Subject A
(note: assessment was 10% tutorials, 15% fieldwork, 75% exams)
Ob = objective A = assignment questions P/F = prac or field work, E =exam question

The Knowledge Dimension	The Cognitive Process Dimension					
	1. Remember	2. Understand	3. Apply	4. Analyse	5. Evaluate	6. Create
A) Factual Knowledge	Ob 2 A				E	
B) Conceptual Knowledge	Ob1 E E	Ob3 Ob4 A E	A P/F	A E	E	
C) Procedural Knowledge	Ob1 L/F		P/F	E		
D) Metacognitive Knowledge						

Table 4: Analysis of Learning Objectives and Assessment Tasks for Subject B
(note: assessment was 10% tutorials, 10% prac work, 80% exams)
Ob = objective A = assignment questions P/F = prac or field work, E =exam question

The Knowledge Dimension	The Cognitive Process Dimension					
	1. Remember	2. Understand	3. Apply	4. Analyse	5. Evaluate	6. Create
A) Factual Knowledge		Ob1				
B) Conceptual Knowledge	Ob 2 Ob 7 A	Ob3 Ob4 Ob5 A	Ob6 A1 A2	A E	E	
C) Procedural Knowledge	P/F	Ob 7 P/F	Ob6 A E	Ob7 A E		
D) Metacognitive Knowledge						

Table 5: Analysis of Learning Objectives and Assessment Tasks for Subject C
(note: assessment was 20% assignments, 80% exams)
Ob = objective A = assignment questions P/F = prac or field work, E =exam question

The Knowledge Dimension	The Cognitive Process Dimension					
	1. Remember	2. Understand	3. Apply	4. Analyse	5. Evaluate	6. Create
A) Factual Knowledge	A					
B) Conceptual Knowledge		Ob1 E		Ob4	Ob3	
C) Procedural Knowledge	Ob2 Ob4 A E	E	A	Ob5 A	Ob2 Ob3 Ob5 E	
D) Metacognitive Knowledge						

Discussion

Analysis of the assessment regimes in three universities clearly shows that there is still a major emphasis (up to 87.5% of assessment in a given year) on exams in civil engineering courses. Only in the fourth year of the courses does the heavy reliance on exams decline in favour of project based work. There was little emphasis on labs and field work, which is rather surprising given the nature of the profession.

As we have explained, emphasis on examinations is likely to encourage students to undertake the type of learning that will lead to success in examinations. Therefore the type of exam questions used becomes a key driver in directing learning. This also means that many of the generic professional skills, which are often not amenable to exam type assessment (e.g. ability to work in teams, some communications skills, research skills) may be de-emphasized.

Analysis of exams questions does not show any trend in terms of the types of questions and levels of cognitive processes required as students progress through their courses. This provokes interesting questions. For example, might one expect more level 1 in first year and more level 3 in final year? Is there any educational basis for this, or just gut feeling? Or is an assumption of level 1 learning what drives the current traditional structure of fundamentals first? As is apparent from Figure 2, there was no particular consistency between the types of questions used at one university for a particular subject with those used at another university for a very similar subject. Again, interesting questions stemming from this finding include: is this lack of consistency a reflection of the approach, attitude or intent of particular lecturers? Perhaps approach to writing exam questions is more localized and reflects accustomed faculty practice? What does this discrepancy say about the likely comparability of student attainment and learning at different faculties across Australia (ie. benchmarking, quality of graduate etc…)?

The exam questions that were judged to be at level 3 questions (requiring evaluation or creativity) were most common overall, closely followed by level 2 questions (application and analysis). The exams that were analysed from the University of Adelaide stood out here as having an unusually high proportion of level 3 questions, especially in the early years of the course. Interestingly, according to the analysis, level 1 questions formed a significant proportion of the exams at the University of Adelaide only in the fourth year of the course.

The findings discussed thus far show a range of levels of cognitive processes required to pass exams in different civil engineering subjects. In the introduction to this paper we made the link between assessment regime, approach to study and likely quality of learning that the student therefore attains. This infers that the higher level exam questions (eg level 2 and 3) are likely to be encouraging students to learn in deeper, richer ways. This is a well supported position, however, success in examinations may still be a poor indicator of an individual student's depth of learning. Pressures of limited time may mean that a student who works slowly and methodically gets fewer marks than a student who works sloppily, but quickly (Felder, Rugarcia and Stice, 2000). Deeper learning can only be measured successfully if students have the opportunity to demonstrate their full understanding, and marks are given accordingly. Heavy reliance on time limited, high pressure exams for assessment may drive students to work on "exam technique" rather than developing deeper learning of the material, and heavy reliance on exams offers a substantial disadvantage to our students who think and know deeply but might take a while to express it.

The third and final component of the research reported here was an analysis of the alignment between stated learning objectives and assessment tasks for selected core subjects in civil engineering (see Figure 3). This comparison was undertaken using the Revised Bloom's Taxonomy and it revealed a number of interesting things. Firstly, the learning objectives for two of the subjects analysed were concentrated in the "remember and understand" columns, with only one subject having objectives spread more widely across the cognitive process dimension. This suggests that for two of the subjects analysed, students were being 'told' (through the learning outcomes) that a surface or rote approach to learning was required. None of the three subjects had an objective that was classifiable under the "create" heading. The analysis of Subject A suggested very poor alignment between the subject's stated learning objectives, and the cognitive and knowledge requirements of the assessment tasks. It is to be hoped that the students in this subject did not take the learning objectives to be an accurate indication of what they were expected to learn and demonstrate by the end of the subject. Subjects B and C showed reasonable overall alignment between objectives and assessment tasks. However, the fact that the weighting of the assessment tasks for all three subjects is 75 to 80% on examination type tasks, indicates that the bulk of the assessment is targeted at only a few of the learning objectives. Given the high weighting of exams, students with the intention of performing well in these subjects would sensibly target a large part of their efforts to exam preparation. The likely result being strong learning in the knowledge dimensions and cognitive processes required for the style of exam question generally set in these subjects.

It should be noted that the points raised are based on limited data, and do not take into account the presentation methods used in each subject, which can affect cognitive processes required to answer an exam question. (e.g. Students may have been given the same question in a tutorial). The effects of institutional policies on assessment methods have also not been considered.

Conclusions:

Analysis of subject outlines from several Australian universities suggests that engineering faculties are still largely reliant on examinations for student assessment. The exams themselves utilize a range of question types, but the very nature of an exam limits its ability to accurately assess some skills. Application of constructive alignment to three core engineering subjects indicates that assessment tasks may not be well matched to learning objectives. The heavy reliance on exams combined with a mismatch with learning objectives could lead to students getting confusing messages about what learning is important, and encourage them to focus on a narrow range of learning designed to maximize exam success rather than meet the overall learning objectives. Application of constructive alignment to subject design could assist academics to modify their assessment practices so that students actively engage with a wider range of learning modes and are better able to achieve the desired learning outcomes.

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