THE ARTICULATION MATRIX

A Tool for Defining and Assessing a Course

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As ever-increasing numbers of students initially attend community colleges, articulation is a concern of public universities. Articulation issues are particularly difficult for engineering design classes, which tend to be institutionally dependent. In Arizona, a task force of university and community college engineering faculty addressed this issue for the first-year engineering design class, and a process, based on the educational research work of Tyler[1] and Bloom,[2] was developed. It involved creating and analyzing an Articulation Matrix—a matrix that shows the educational relationship between a course's learning activities and learning objectives. One strength of the developed process was the creation of an explicit assessment process to determine if a proposed course was acceptable.

CREATING THE ARTICULATION MATRIX

In Arizona, the first-year engineering (design) course is a cornerstone in each of the three state university's BS engineering curriculum. Since introductory design courses do not generally have the type of defined learning objectives found in a statics or dynamics course, these introductory courses tend to be unique at each of the three universities. With the large number of students who want to take the first-year engineering course at a community college, the three unique courses have made it very difficult for the community colleges to offer a course that could transfer to all three universities. The community colleges have been forced to select the university most of their students are likely to attend and then develop a course consistent with it. Articulation problems extend beyond community colleges to include all course transfers between schools of engineering.

In the fall of 1996, a task force* of faculty from the three universities and several community colleges started work on this articulation problem. They were faced with the standard articulation issues of

- *What topics, skills, etc., to include in the first-year design course*
- *How to ensure (establish) that a proposed course was, in fact, satisfactory*

and, a third issue to be considered

- *How to address the first two issues in a manner such that a school still had the flexibility to develop its own unique character for the course, using the school's interests and strengths.*

The task force developed a process that satisfactorily addressed all three of the issues. The process requires the creation and use of an Articulation Matrix, so called because it helps resolve the articulation problem.

This paper will first present the educational theory upon which the Articulation Matrix is based, followed by a general discussion of the Articulation Matrix and how to create and analyze it. It will conclude with two examples, one showing how the matrix was used in the articulation process and one showing how the matrix could be used as part of an ABET EC 2000 accreditation effort.

THE EDUCATIONAL THEORY

The educational basis for the Articulation Matrix comes from the published work of two School of Education faculty members at the University of Chicago, Ralph Tyler[1] and Benjamin Bloom.[2] Tyler formulated a basis for defining a course or curriculum, while Bloom worked to clarify the

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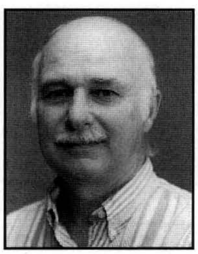

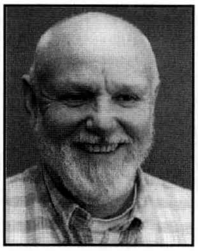

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terms used in describing how well a subject has been mastered.

Defining a Curriculum (Course) • Criterion 2 of ABET EC 2000[3] requires a school to have and use a defined process for the development and continuous improvement of its curriculum. How to satisfy Criterion 2 has created a rash of interest and a plethora of papers and workshops. But the issues involved in Criterion 2 are not new and were addressed in the late 40s by Tyler. In 1949, he published a short treatise on the basic principles involved in curriculum and instructional development. His work is neither a textbook nor a manual on curriculum development, but rather the "rationale for viewing, analyzing, and interpreting the curriculum."

Tyler's approach involves answering four basic questions:

1. *What educational purposes should the school seek to attain?*
2. *What educational experiences can be provided that are likely to attain these purposes?*
3. *How can these educational experiences be effectively organized?*
4. *How can we determine whether these purposes are being attained?*

Criterion 2 requires schools to: define a set of learning objectives (*i.e.,* answers to question 1); define a strategy to accomplish the learning objectives (*i.e.,* answers to questions 2 and 3); and define an assessment process to measure achievement of the learning objectives (*i.e.,* answers to question 4).

Learning Objectives—Two-Dimensional Vectors • The first step in defining a course or curriculum is development of a set of learning objectives, sometimes called learning outcomes. At first glance, the exemplar learning objectives published in the literature appear to be one-dimensional, *i.e.,* only a subject, topic, or skill to be learned.[4,5] But upon closer observation, the objectives also define some level of performance associated with the competency (*e.g.,* "graduates will be able to identify, formulate, and solve..."[4] or "will exhibit good listening skills"[5]).

Learning objectives are two-dimensional vectors consisting of a competency and a degree to which the competency is learned or mastered. Of these two parts, the first is the easiest to define precisely. The competency is the subject, topic, or skill to be learned (*e.g.,* integration by parts). Precisely defining the degree to which a competency is mastered is more difficult. For example, what does "really understands integration by parts" mean? While this example could be improved and made more specific, the effort is probably not worthwhile, especially if every competency needs its own special wording. Rather, what is needed is a concise, precise, agreed-upon set of terms that can be used to define the degree to which any competency is mastered.

In the mid-50s, Benjamin Bloom, David Krathwohl, and others addressed this problem and developed two taxonomies of educational objectives, one for the Affective Domain[7] and one for the Cognitive Domain.[2] In the foreword to the Cognitive Domain book, Bloom states that the book was "especially intended to help them [those involved in the development of curriculum and courses] discuss these problems [defining how much is learned] with greater precision," which is exactly what is needed. (While this paper only addresses the cognitive domain, understanding the affective domain is a precursor to appreciation of the cognitive issues.)

The cognitive taxonomy was developed assuming that

- *There are different degrees of learning to which someone can know and use information*
- *The different degrees of learning are observable and measurable*
- *The degrees of learning are reasonably hierarchical*

The first and second assumptions reflect the observation that there are noticeable, measurable differences between a novice and an expert in how they use information. The third assumption is based on the observation that successful demonstrations of the higher degrees of learning are generally not possible before successful demonstrations of mastery of the lower levels.

In the early 1990s, David Langford[8] updated Bloom's taxonomy, renaming the learning objectives to Levels of Learning (LoL). The six Levels of Learning, from lowest to highest, are: *Knowledge* (K), *Comprehension* (C), *Application* (Ap), *Analysis* (An), *Synthesis* (S), and *Evaluation* (E).

Bellamy and McNeill[9,10] modified Langford's definitions to reflect the type of activities found in engineering education. An example of how the *Knowledge* Level of Learning is described can be seen in Table 1 (following page). The description includes information from both the student's and the teacher's point of view. The list of *process verbs* at the end of the description is very helpful in distinguishing between the various levels of learning.

OVERVIEW OF THE ARTICULATION MATRIX

The Articulation Matrix is a concise way of presenting the answers to Tyler's first two questions. Further, it presents the data in a manner that makes it possible to also partially answer Tyler's third and fourth questions. The matrix consists of a set of rows (the learning objectives), a set of columns (the class activities) and a set of letters indicating the LoL impact, if any, each activity has on each learning objective (see Figure 1, which will be discussed later). Tyler included an early version of the matrix on page 50 of his book. To better understand the matrix, consider how it is used to help answer each of Tyler's four questions.

Question 1: Defining the Learning Objectives • Answering the first of Tyler's questions requires stating the course's learning objectives (competencies and associated changes in LoL). The processes used to generate the learning objectives are many and varied (*e.g.,* 4, 5, and 6) and will not be discussed here. Once the learning objectives have been developed, they can be entered into the Articulation Matrix. First, the competencies are entered. Since there is often a hierarchy associated with the competencies, the matrix allows for this by having *Competency Categories* as well as *Competencies* under each of the categories. Thus, in Figure 1, there are two major competency categories (Engineering Design Process and Working in Teams) and eight competencies (*e.g.,* formulating the problem, team communication) shown.

Next, to complete the entry of learning objectives, the change in LoL for the *Competency Categories* and *Competencies* must be entered. The change in LoL is indicated by showing the required input level and the desired output level in the second and third matarix columns. Thus, in the matrix shown in Figure 1, the change in LoL for "solving a problem" (competency 1.2) is from *Unaware* (a "U" in the second column) to *Application* (an "A" in the third column).

Question 2: Defining Course Activities and Their Impact • Once the learning objectives have been entered, it is possible to answer Tyler's second question. This is generally an iterative process with the completed matrix showing the results of the final iteration. The general process involves adding all the class activities, one at a time, to the matrix, indicating in the body of the matrix which learning objectives are impacted by the activity, and finally indicating the degree of learning possible using the activity.

Consider the fourth activity, "orally report to peers and class," shown in Figure 1. When this activity was entered into the matrix, it was felt that it impacted all the shown competencies except for competency 1.5. Further, the impacts were all judged to be at the *Comprehension* LoL; that is, the "C" in the "solving a problem" competency row indicates that when the activity is completed, the students could have demonstrated mastery of "solving a problem" at the *Comprehension* LoL. This example matrix is rather dense, *i.e.,* many of the activities impact on many of the learning objectives. It is not uncommon to have less dense matrices.

There is an alternative, somewhat easier but less educationally rigorous, method for completing the matrix. In this alternative method, the competencies are loosely viewed as the *needs* and the activities as the *hows* in a House of Quality.[11] Thus, in filling out the matrix, instead of indicating the LoL, a symbol indicating the degree of impact (high, medium, low) that the activity has on the competency is entered into the matrix. This method does give a good picture of which activities have the biggest impact on the learning, but a matrix completed using this method is much harder to use when attempting to address Tyler's last two questions.

Question 3: Organizing the Course Activities • Since the previous step focused only on entering all the course activities into the matrix, the columns in the matrix are generally not in the desired order, *i.e.,* the actual sequence followed in the course. This can be seen in Figure 1 where there are "Out-of-Class Activities," shown late in the matrix, that would actually occur early in the course (*e.g.,* "read and summarize textbooks"). While the matrix may not have the activities organized, it does contain information that can be

TABLE 1
Activities of Students and Teachers at the Knowledge Level of Learning[10]

Knowledge (Information) Level of Learning

- How do **I know** I have reached this level?

  I can recall information about the subject, topic, competency, or competency area; I can recall the appropriate material at the appropriate time. I have been exposed to and have received the information about the subject; thus, I can respond to questions, perform relevant tasks, etc.

- What do **I do** at this level?

  I read material, listen to lectures, watch videos, take notes; I pass "true/false," "yes/no," "multiple choice," or "fill in the blank" tests that demonstrate my general knowledge of the subject. I learn the vocabulary or terminology as well as the conventions or rules associated with the subject.

- How will the **teacher know** I am at this level?

  The teacher will provide verbal or written tests on the subject that can be answered by simply recalling the material I have learned about this subject.

- What does the **teacher do** at this level?

  The teacher directs, tells, shows, identifies, examines the subject or competency area at this level.

- What are typical ways **I** can demonstrate my knowledge?

  1. *Answer "true/false," "yes/no," "fill in the blank," or "multiple choice" questions correctly.*
  2. *Define technical terms associated with the subject by stating their attributes, properties, or relations.*
  3. *Recall the major facts about the subject.*
  4. *Name the classes, set, divisions, or arrangements that are fundamental to the subject.*
  5. *List the criteria used to evaluate facts, data, principles, or ideas associated with the subject.*
  6. *List the relevant principles and generalizations associated with the subject.*
  7. *List the characteristic methods of approaching and presenting ideas associated with the subject (e.g., list the conventions or rules associated with the subject).*
  8. *Describe the general problem-solving method (i.e., the techniques and procedures) or the method(s) of inquiry commonly used in the subject area.*

- What are typical **work products**?

  1. *Answers to Knowledge-level quizzes ("true/false," "yes/no," "fill in the blank," or "multiple choice").*
  2. *Lists of definitions or relevant principles and generalizations associated with the subject.*
  3. *Modifications of example problems presented in the textbook; for example, modest changes in numerical values or units; i.e., solutions to problems that were solved using "pattern recognition."*

- What are descriptive **"process" verbs**?

define	label	listen	list	memorize	name
read	recall	record	relate	repeat	view

used to help establish some of the desired organization.

Tyler suggests that the two major course organizational considerations are 1) how to organize for the continual growth in LoL for a competency, and 2) how to organize for cross-competency requirements (*i.e.,* pre- and/or co-requisite competencies). The Articulation Matrix can help with the first, but not the second, of these considerations. Assuming Bloom's taxonomy is hierarchical, the activities for a competency need to be scheduled to begin with the lowest LoL and proceed sequentially to the highest LoL. Thus, the matrix shown in Figure 1 suggests that for the "formulating the problem" competency, the *Knowledge* activities should occur early, the *Application* activities should occur late, and the *Comprehension* activities should occur in between.

Question 4: Assessing the Course • Tyler's fourth question concerns assessment. While the Articulation Matrix is not directly concerned with student assessment, it can help in two assessment areas. First, the matrix can be used to pre-assess the course to determine if it has the potential of delivering the desired objectives. Second, the matrix can help select assessment instruments for the various course activities.

Pre-Assessment of the Course. After all the course activities have been entered and their impact entered in the matrix, the matrix can be evaluated to confirm that the proposed course is complete and has the potential to allow students to achieve the predefined learning objectives. In pre-assessing the course, there are four considerations:

1. *Is there at least one course activity that impacts each of the competencies (i.e., no empty rows)? If there are empty rows, one or more course activities must be added to the matrix or an existing activity must be modified so it impacts the competency.*
2. *Is there at least one competency impacted by each course activity (i.e., no empty columns)? If there are empty columns, the course activity does not impact any of the course learning objectives and should be eliminated.*
3. *Does each row have an adequate number of appropriate course activities? If the competency has an expected multilevel change in LoL (e.g., from* Knowledge *to* Analysis*), are there activities at the intermediate LoL's (e.g.,* Comprehension *and* Application*) as well as the final expected level (e.g.,* Analysis*)? Are there too many or too few activities at any given level? Any "No's" must be addressed by adding or removing activities, modifying other activities so they impact the problem competency, or changing the LoL associated with the competency to match what is actually possible.*
4. *Do at least 75% of the competencies for a competency category have course activities at the LoL stipulated for the competency category? If the answer is "no," then either more activities at higher LoL must be added or the competency category LoL must be reduced to match the LoL of the activities shown in the matrix.*

Competencies	Level of Learning (in)	Level of Learning (out)	Course Activities	In Class Activities	take quizzes/exams before class	active learning exercises	construct mathematical models	orally report to peers and class	peer assess design notebooks	work on design projects	watch manufacturing/other videos	listen to brief lectures	Out of Class Activities	read and summarize textbooks	construct model based on geometry	Projects	dissect and reassemble artifact	develop an assembly plan (process)	design, build, and test a device	demonstrate design
1. Engineering Design Process	U	A																		
1.1 formulating the problem	U	A			K	C		C		C		K		K			C	C	A	A
1.2 solving a problem	U	A			K	C		C		C		K		K			C	C	A	A
1.3 implementing a solution	U	A			K	C		C		C		K		K			C	C	A	A
1.4 documenting the process	U	A			K	C		C		C		K		K			C	C	A	A
1.5 using engineering/physical principles	U	K					K													
1.6 using quality principles	U	A			K	C		C		C		K		K			C	C	A	A
2 Working in Teams	U	C																		
2.1 team dynamics	U	C			K	C				C		K		K			C			
2.2 team communication	U	C			K	C				C		K		K			C			

Level of Learning Legend U Unaware K Knowledge C Comprehension A Application

Figure 1. *A portion of ASU's first-year design course Articulation Matrix.*

The first two are easy checks and help ensure that all the course learning objectives are addressed in one or more of the activities and that there are no extraneous activities (*i.e.,* activities that have no impact on the desired learning objectives). The answers to the third and fourth questions are a bit more subjective. The third assessment question focuses on each competency, to ensure that there are enough activities at the appropriate LoL's so a student could reasonably be expected to achieve the desired LoL by the end of the course. The fourth question focuses on whether there are enough course activities at a high enough LoL to ensure that the entire competency category LoL is achieved. The use of 75% is somewhat arbitrary and may be modified with experience.

Assessing the matrix shown in Figure 1 leads to the following conclusions. First, each row has at least one activity that impacts on the competency. Second, there are two activities ("peer assess design notebooks," "watch manufacturing videos") that appear to impact no learning objectives and should be considered for removal (they actually impact several competencies not shown in this partial view). Third, the mix of activities for each competency is good. For example, there are three *Knowledge*, five *Comprehension*, and two *Application* activities for the first set of competencies. It is possible that there are actually too many *Comprehension* activities. Finally, the competency LoL's support their competency category LoL's. For example, five of the six competencies (83%) under the "Engineering Design Process" competency category have activities at Application LoL, which is the desired LoL for the competency category. It would appear that this course is acceptable and should articulate.

Assessment Instruments. Once the expected LoL is known for an activity, the method of assessing whether the students have achieved the LoL needs to be determined. As with the learning objectives, the requirements of EC 2000 have spawned many articles and workshops on assessment. Since the LoL of the activity has been defined, there are several places to find appropriate assessment instruments. First, the work by Angelo and Cross[12] on classroom assessment can be reviewed. Next, Bloom[2] can be reviewed; it contains a number of typical testing methods that can be used for each LoL. Third, the definitions of the various LoL's[9,10] provide a variety of different ways of looking at each LoL, allowing the generation of appropriate assessment instruments. For example, material for *Comprehension* LoL[9,10] states that students should be able to explain (orally or written) their solution process. This suggests that for *Comprehension* LoL activities, a discussion of the process should be required.

USING THE ARTICULATION MATRIX

While the Articulation Matrix was developed to resolve the first-year engineering design course articulation problem, it has become clear that it has a wider application. Two applications will be discussed: one that uses the matrix in course articulation and one that uses it as part of the EC 2000 accreditation process.

Course Articulation Within a State • The starting point for this work was the fact that design courses did not articulate at the three state universities. The task force developed a two-step process to resolve this problem. In the first step, the task force defined the desired learning objectives (six competency categories and twenty-two competencies) and entered them into a blank matrix, creating a "skeleton" Assessment Matrix (Figure 1 shows part of this matrix; see Reference 13 for the complete skeleton matrix). Much of the task force's work involved explicitly defining the learning objectives and developing a complete glossary of operational definitions[13] ("operational definition" is the agreed-upon meaning of the term) for each *Competency Category* and *Competency* in the matrix. Finally, the task force added several topic and activity constraints to ensure the course included the desired type of experience (*e.g.,* at least two extensive, 3-to-6-week projects). Once the skeleton matrix was completed, the task force was done; the various schools then completed the matrix during step two of the process.

In the second step of the articulation process, each school (university, community college) that wanted to offer a course that would articulate started with the skeleton matrix and constraints and then completed and assessed an Articulation Matrix for their proposed course. The task force developed an assessment checklist to aid in the assessment step. Any course that passed the assessment step would articulate at all of the three state universities.

The strengths of this process are twofold. First, having each school start with the skeleton matrix allows considerable flexibility in defining how the learning objectives are met. Each school can use activities that suit its nature and strengths. The only constraint is to have enough activities at the appropriate LoL. Second, having a defined assessment step takes the uncertainty out of the articulation process. A community college need no longer wonder if its course is satisfactory. Any questions that do arise (*e.g.,* Does that activity actually allow *Comprehension* LoL?) can be easily resolved by supplying samples of student work for the activity in question.

EC 2000 Accreditation Process • While experience to date has been primarily limited to using the matrix to resolve articulation problems, the process of developing the matrix is general and can be easily extended to defining a curriculum (*e.g.,* the Mechanical and Aerospace Engineering Department at Arizona State University has developed the curriculum matrix for its two undergraduate degrees). When using the matrix for a curriculum, the following changes are made:

1. *The learning objectives, i.e., the rows, are the objectives related to the entire curriculum and not just a course.*
2. *The columns become the courses in the curriculum instead of class activities.*
3. *The LoL impact indicates the maximum LoL expected to be achieved in the course.*

Part of the matrix for a chemical engineering curriculum is shown in Figure 2. Looking at the rows, the curriculum shown in the figure shows that the students are expected to enter the curriculum at *Unaware* and to leave at *Synthesis* LoL for "Modeling." How this transformation is accomplished is partially shown by looking at the two modeling sub-competencies. The students are expected to achieve *Knowledge* LoL about "conservation and accounting" in their first-year chemistry courses and *Analysis* LoL in ECE 201.

Competencies	Level of Learning (in)	Level of Learning (out)	English 101 and 102	General Studies	Economics 111 or 112	Chemistry 113	Chemistry 116	Chemistry 331 (organic)	Chemistry 332 (organic)	Chemistry 335 (organic lab)	Mathematics 270 (differential calculus)	Mathematics 271 (integral calculus)	Mathematics 272 (series)	Mathematics 274 (ODE)	ECE 100 (introduction to design)	ECE 300 (intermediate design)	ECE 201 (conservation principles)	ECE 202 (properties of mater)
1. Fund. Math & Science	K	Ap																
1.1 calculus	U	Ap									C	C	C	C			Ap	Ap
1.2 general chemistry	K	Ap				C	C									Ap		
1.3 organic chemistry	K	Ap						C	C	Ap								
2. Modeling	U	S																
2.1 principles of modeling	U	S													C	Ap	Ap	Ap
2.2 conservation & accounting	U	S				K	K										An	

Level of Learning Legend
U Unaware; K Knowledge; C Comprehension; Ap Application; An Analysis; S Synthesis; E Evaluation

Figure 2. *Part of an Articulation Matrix for a chemical engineering curriculum.*

The "principles of modeling" are developed to the *Comprehension* LoL in the first-year design class and are then demonstrated at the *Application* LoL in the upper-division classes.

Looking at the columns of the matrix is also instructive. Figure 2 shows that the conservation principles course (ECE 201) is expected to offer the students a chance to demonstrate *Application* LoL for "calculus" and "principles of modeling," and *Analysis* LoL for "conservation and accounting" modeling. How the course might achieve these LoL goals is not shown in the matrix; this information would be shown on the course matrix.

As with the course matrix, the curriculum matrix can be used to sequence courses. The matrix in Figure 2 shows there are six courses that have an impact on the calculus competency. Based on the LoL shown in the matrix, it appears that Mathematics 270, 271, 272, and 274 should come before ECE 201 (*i.e., Comprehension* before *Application*). The "calculus" row in the matrix highlights the expectation that students are **not** entering ECE 201 with the ability to recognize when to use the calculus skills they have learned (*Application* LoL); rather, *Application* LoL for "calculus" will be achieved in ECE 201 and other upper-division courses.

Finally, the potential success of the curriculum can be assessed much as a course is assessed. For the curriculum, the third assessment question concerns whether there are, realistically, enough courses to move the students through the desired change in LoL. It is reasonable, at the lower LoL's, to expect to be able to move a student through three (and possibly four) levels in one course. But for the higher LoL's, it is difficult to move through more than one or two levels per course. It is not reasonable to expect to take a student from *Unaware* through *Synthesis* or *Evaluation* LoL in a single course. The matrix in Figure 2 is clearly not complete; there are no courses shown at the *Synthesis* LoL for any of the "modeling" competencies.

The use of a matrix to define a curriculum is not new. Olds and Miller[4] defined just such a matrix. The mapping between our matrix and that of Olds and Miller is simple. Their "Program Objectives" become the *Curriculum Competencies*, the "Implementation Strategies" become the courses in the curriculum, and the "Performance Criteria" and "Assessment Methods" become the LoL designations. An advantage of the articulation matrix is that it facilitates assessment of the curriculum.

One final note: it should be possible, using a set of Articulation Matrices, to create a highly compact integrated picture of a curriculum. The first Articulation Matrix in the package would be the curriculum matrix. Then, using the curriculum matrix's *Competency Categories* and *Competencies* as the skeleton matrix, the Articulation Matrices for each course in the curriculum would be created. The desired LoL changes for the course Competencies would come from the LoL changes shown in the body of the curriculum matrix. For example, if the curriculum matrix is that shown in Figure 2, then the course matrix for ECE 201 would show "An" (*Analysis*) for the LoL (out) column and "K" (*Knowledge*) for the LoL (in) column for "conservation & accounting" competency. This package of matrices documents the integrated nature of a curriculum, something required by ABET EC 2000.

SUMMARY

A process that allows Arizona's universities and community colleges to independently develop a first-year engineering design course that will articulate at all of the state's three universities was the focus of this paper. The process uses an Articulation Matrix that shows the educational relationship (Level of Learning achieved) between a course's learning activities and its learning objectives. The matrix was developed using the educational research of Tyler and Bloom. A strong point of the process was development of the assessment method used to determine if a course is acceptable (*i.e.,* allows the students to achieve the course learning objectives). The matrix can be used for any course and is a good way to evaluate a course syllabus. A similar matrix can be used to show how curriculum competencies can be defined, an EC 2000 task.

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