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Adaptive Tests as a Tool for Evaluating Work Groups in Engineering*

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The development of adequate work group activities in engineering is a tough task, and their efficiency can be highly influenced by students' attitude. In this article, an evaluation of teamwork (chemical and computers laboratories) related to Chemical Engineering subjects is presented, as well as the conditions for an effectual development of work groups and students' attitude for guaranteeing an efficient learning. By using adaptive tests, the most effective self-regulated learning strategies and their relationship with work groups is defined. By doing so, it is demonstrated that teamwork can be helpful for students, but it is not risk free if students do not focus on the tasks. In this sense, results show that students with a passive attitude in the group reach minimal scores, i.e., do not learn concepts or, even do not pass the final examinations.

Keywords: adaptive tests; chemical engineering experimental activities; teamwork

1. Introduction

The use of technology opens new frontiers in learning and improves data mining from students, allowing us to develop and analyze learning strategies [1]. A paradigmatic example of the potential of communication technologies in learning is the Massive Open Online Courses (MOOC) [2, 3], where a large number of students can be involved and makes manual monitoring of learning unfeasible. Information technologies convert this kind of initiatives viable since data processing can be performed without real-time supervision of teachers. Another resource easily applied by computers is the use of numerical calculations to simulate realistic scenarios that are not easily accessible [4, 5].

Moreover, one of the biggest challenges of including communication technologies in learning is the substitution of interaction between teachers and students by automatic procedures [6, 7]. A concept that aroused great interest is tutoring and the possibility of turning an automatic system to an effective instrument for counseling and controlling students [8, 9]. Yet, designing an effective automatic tutoring system requires also being familiarity with the most effective learning strategies.

Engineering degrees include experimental disciplines in most of the courses that comprise the academic background of the future engineers. Engineering learning has specific attributes, such as analysis, constraints, modeling or optimization, and requires certain engineering mindsets such as accepting multiple possible solutions and the utility of productive failure [10]. In the specific case of the chemical engineers, its training is focused on bringing capability of conceiving, designing and operating chemical-industrial facilities. Experimental learning and teaching can also help the progress of a viable engineering for empowering a global sustainable development [11].

Most of the experimental activities carried out by the chemical engineering students are programmed to be executed in groups. Working in groups can be related to the limited resources in laboratories. Moreover, experimental activities are complex and the cooperation among schoolmates allow them to share the tasks. We should take into account also that engineers must acquire competences related to the ability of working effectively, both individually or as a team and working in multidisciplinary environments such as establishes the requirements for the verification of the official university degrees that qualify for the exercise of the profession of Engineer [12]. These competences are currently included in teaching guides; thus, they must be assessed properly.

If a group work well together, each classmate can achieve much more than working individually, accordingly it can be advantageous working together (a–c), although also some disadvantages can be detected (d–f), as the study guide from the University of Leicester collects [13].

(a) Increasing productivity and performance: in fact, practical activities should allow students to share and discuss ideas.
(b) Skills development: being part of a team can help schoolmates to achieve different roles such as leadership, and working with and motivating others, which can be useful not only at academic but at a professional level.
(c) Strengths and weaknesses identification: work-

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ing in groups can help students to identify the role into a group, for example, if they are better leader than listener, or better coming up with the 'big ideas' than developing them.

(d) Unfair division among different group members': If someone feels they are doing all the hard work, this can lead to resentment.
(e) Conflict between different group members: this might arise for many different reasons including leadership competition.
(f) Tackling inappropriate tasks as a whole group: groups are not good environments for carrying out some activities such as writing first drafts, which are usually better developed individually.

In this article, we analyze data from different theoretical and practical tasks carried out individually or by groups, in order to measure the influence of teamwork in engineering learning. We use adaptive tests to measure parameters such as attention or motivation. For measuring experimental activities carried out by groups, we use traditional assessment tools (previous knowledge of the theoretical and experimental basis; autonomous management of the experimental installation; attitude, motivation and teamwork; critical analysis of the data obtained; content and format of the report; correction of the answered questions). These data are complemented with assessment by theoretical examination performed by the students before and after the experimental practices, where students worked in groups. All these data allow us to quantify the influence of the practical sessions on the students training, determining the most adequate strategies to maximize the benefits of group assessment.

2. State of the Art

The inclusion of new technologies in the learning process gives teachers the opportunity of using new tools in the assessment of many different skills [14]. Work group skills are not an exception. A very interesting example is the use of wikis, that are websites that eases the collaborative development of interlinked web-pages. The massive collaboration process between students that can modify the contents from different places produces great amounts of data related to collaboration skills of students with the advantage of avoiding the problem of having them located in the same place [15]. However, traditional assessment methods do not scale well and new techniques that include self-assessment or involved students in different ways have been proposed [16, 17].

Since the main objective of this article is to analyze and identify the most common and efficient learning strategies when working in groups, we must focus on the best way of measuring students' activities. In the past, self-reported surveys have been commonly used for data collection [18]. However, it contains errors since students are directly involved in the learning process and are subjective due to of their own involvement in the learning activities. In this scenario, developing learning activities that can be easily monitored and give accurate information about students' performance is necessary. A great candidate for this task is Computer Adaptive Testing (CAT) since of its ability to adapt the content presented to learners as a function of their responses [19]. CAT has been commonly used in a wide variety of courses and activities: language [20], identification of learning styles [21] and programming [22] are a few significant examples. However, the advantages of using CATs in learning implies also a deep knowledge of the numerical models underneath to make a good calibration of the system [23].

Learning online increases the importance of Self-Regulated Learning (SRL) since many activities that previously were possible only in presence of teachers can be done now autonomously. In this scenario, one of the concepts that has been widely studied is the importance of attention when learning using online tools [24]. It has been also described the potential risks of digital devices when students use these technologies wrongly [25] and their use reduces students' focus on learning tasks. For these reasons, parameters related to attention are crucial when analyzing different students' attitudes when working in teams, which is the main topic of this article.

3. Methodology

3.1 Adaptive test application

The adaptive system proposed in this article has been developed with a view to providing a system of self-assessment that can also be used as a system for final student assessment. This system has the advantage of highly increasing student's motivation for using the system throughout their learning phase. In Fig. 1 we show the teacher's interface of the adaptive tests application (e-valUAM). As we can observe, one of the options when creating questions is to include a Matlab file to calculate the correct answer. This is a very important fact since it allows the system to give different possible answers each time and students should make new calculations every time. By doing so, we are sure that they do not answer by memorizing the numerical answers.

In Fig. 2, we show the interface of e-valUAM for students. As we can see in the figure, students must answer the questions, after reading them without taking care of the configuration of the free para-

Fig. 1. Graphic e-valUAM interface for teachers in the "Add new question" section.

meters (see Fig. 1) since this is an internal process. In the case of the question shown in Fig. 2, the free parameter is "a" and it takes a value of 4.447. This value will be changing randomly between two limits (set by the teacher).

This format is an adequate option for detecting students' attention. The results of a test include information about the time spent in every question, the answers and the final results of the test. In this way, if a test has not been completed, and containing only general answers, such as simple numbers (0, 1...), it would mean that the student only took a look at the questions without working seriously on them. On the other side, a test finished with not only simple numbers imply attention to the task by the student. Those conclusions are also supported by the analysis of the spent time to answer.

3.2 Subjects Included in the Experiment

The data used in this article are collected from two subjects that belong to the Chemical Engineering Degree of Universidad Autónoma de Madrid (Spain). The first data set were acquired from students of the 2017/2018 academic year in the first-year subject "Applied Computer Science". 73 students were involved. This subject, which corresponds to 6 ECTS, was taught through theory lessons and practical classes. The practical classes were carried out in computer laboratories, individually and supported by an adaptive test developed in the e-valUAM platform, as pointed out above [26]. In this subject, we have developed a test with 20 questions divided in four levels (the repository includes 50 different questions). Every time a student answers five questions correctly, the system starts selecting questions from the repository of the following level. Since the use of this practical resource is always individual, this first subject will serve essentially to evaluate the usefulness of computer-oriented practical activities.

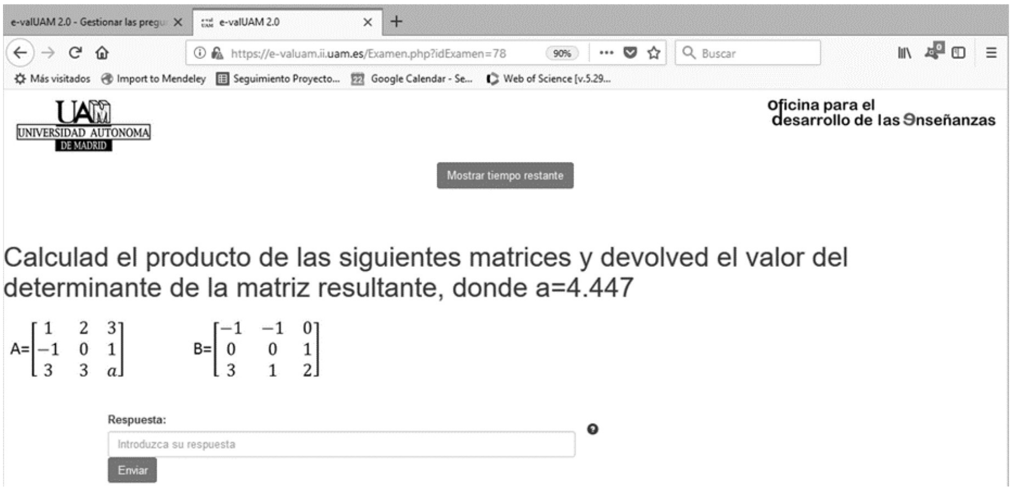

Fig. 2. Graphic interface shown to students during a self-assessment test.

To analyze the effect of working groups in practical activities, we have also obtained data from the subject “Design of Water Treatment Facilities” in the course 2017/2018. It is an optative 6 ECTS subject included in the 4th course of the degree. In this subject, we took data from 23 students.

3.3 Teaching Methodology

The teaching methodology includes:

1. Theoretical and practical lessons in the classroom. The theory of the subject is divided in four sections covering the treatment of urban and industrial wastewater as well as water purification and regeneration. Practical exercises are proposed, most of them are solved at the classroom.
2. Chemical laboratory sessions. Experiments in the chemical laboratories are developed by groups conformed by three-four students, being them free to organize the groups. Outlines of the two experimental activities (including the aim of the session, a short introduction, the experimental set-up and procedure) are available for the students, before the laboratory sessions are carried out. The experimental activities are related with the theory lectured in the classroom. Specifically, they study:
   (a) The operation of a sequencing batch reactor for the treatment of municipal wastewater, determining key parameters of the process.
   (b) The treatment of a real industrial wastewater by coagulation-flocculation, optimizing the reagent doses.
3. Practical lessons with computers. Numerical simulations are developed in pairs. They are free to choose their team partners. The undergraduates use WEST, a modelling software for static and dynamic modelling and simulation of wastewater treatment plants.
4. A mandatory visit to a wastewater treatment plant. After theoretical classes, the students visit a wastewater treatment plant to identify, in situ, the different aspects studied during the course.

3.4 Assessment Steps

The assessment includes the following elements:

1. Written examination, including the whole contents from the theoretical lessons. The tests include questions related to the theoretical contents and numerical problems. The students should give reasonable answers including information about the steps that must be done to solve the problems.
2. Reports of the experiments developed at the laboratories. These reports are guided by a set of short questions that students should fill with the results obtained in the experiments. Moreover, some discussion about the results obtained and how to improve them must be provided. The reports are presented by the whole group.
3. Reports of the computer laboratories. Such as for chemical laboratories, a document that works as a guide for the students should be filled with the results obtained in the numerical simulations. The reports are developed in pairs.

3.5 Tests Adapted to the Nature of the Contents

The autonomous learning was supported by different adaptive tests included in the e-valUAM platform. Due to the different nature of the subject contents’, as it has been above commented (theoretical and numerical problems), four tests were developed in different formats to fit the intrinsic requirements of the contents. For the theoretical contents, multiple choice tests have been proposed. These tests include three possible answers. To solve the numerical problem, the adaptive test format implies open answers instead of multiple choice, following the explanation earlier mentioned. Two tests were developed for theoretical content and another two for numerical problems, including different parts of the subject, with direct correspondence with two stages of the subject that were independently evaluated with theoretical examination. At the end of the course, an additional written final exam was included in the assessment process. The adaptive tests were configured as follows:

1. Theoretical test for stage 1: A complete repository of 46 questions divided in four levels. Students must answer 16 questions (the adaptive test jumps to a new level every 4 correct answers).
2. Numerical problem test for stage 1: A complete repository of 12 questions divided in 3 levels. Students must answer 6 questions (the adaptive test jump to a new level every 2 correct answers).
3. Theoretical test for stage 2: A complete repository of 44 questions divided in 3 levels. Students must answer 18 questions (the adaptive test jump to a new level every 6 correct answers).
4. Numerical problem test for stage 2: A complete repository of 18 questions divided in 3 levels. Students must answer 9 questions (the adaptive test jump to a new level every 3 correct answers).

4. Results

In Fig. 3 we compare the final assessment (i.e., scores in the final examination) of the whole group in the subject “Applied Computer Science” with three parameters related to the learning stage. Firstly (Fig. 3A), we compare final scores with the total amount of time invested using the application. Secondly (Fig. 3B), we compare final scores with the number of times students used the application. In this case, we have included all the attempts, without excluding anything. In other words, we have counted all the times the students start a test, even if they do not finish it. Finally (Fig. 3C), we have counted the number of real attempts, which means attempts that were finished. These attempts are of huge relevance to this kind of system, because answering questions of our test implies a mental effort and some mathematical calculations, i.e., completing tests implies a considerable effort for students and are an adequate measurement of the focusing of students in the task.

As Fig. 3 shows, the three measured magnitudes indeed correlate (R > 0.45) with the final scores.

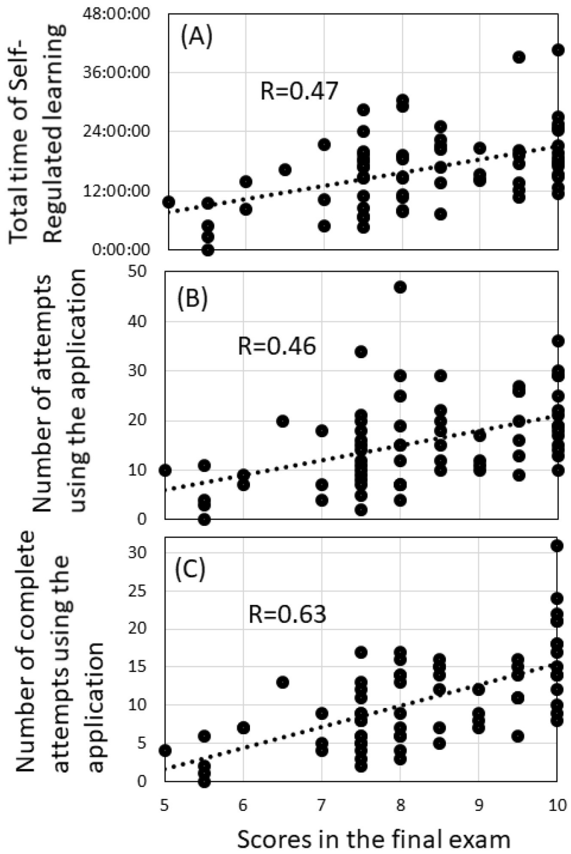

Fig. 3. Comparison of different parameters related to Self-Regulated learning with the scores in the final examination from the subject Applied Computer Science.

However, the correlation was only medium-strong (0.63 of correlation coefficient) in the case of completed attempts, which involves active participation of students in programming and mathematical calculations. Ergo, we conclude that this kind of activities are only useful with an active participation of students.

In Fig. 4, we show the time spent for a student of Applied Computer Science to finish the test since they started to study the subject until the final examination (marked point), when reached the highest grade. The figure shows a jump at the point corresponding to the first attempts of the student that involves complex programming questions. Before this point, the student had not yet received enough information in the theoretical classes to face these questions. A clear decreasing in the invested time occurring after this point indicates that the student is learning those difficult contents. The increasing in the scores also supports this fact. It is worth pointing out that these conclusions can be only obtained by using adaptive tests since the order of the questions presented in the test gives us an accurate description of what is happening at every point of the learning phase.

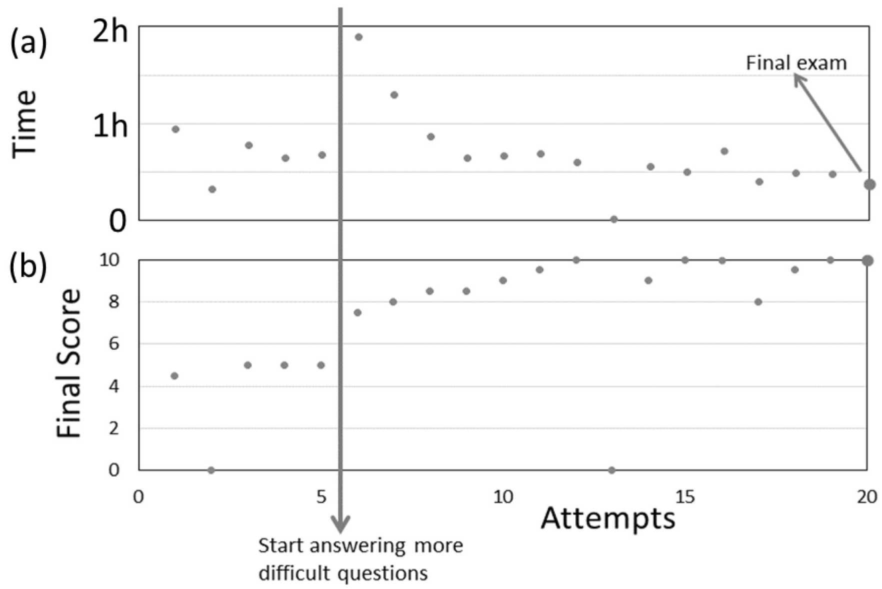

Fig. 4. Time invested using the online application as a function of the attempts number.

At this point we can conclude that using supporting tools, like computers, in learning is useful only if students pay enough attention to the task. In other words, students need to be active and focused on the practices. After that, we are going to check the validity of this hypothesis for working groups.

In the subject "Design of Water Treatment Facilities", the laboratory computer sessions with the software WEST, the students were divided in 10 pairs. Taking into account the scores of the final examination, those pairs have been divided into two clusters. In other words, we have ordered the students inside each group by their scores in the final examination, obtaining a group of "clever" students (group 1) and a group of "lazy" students (group 2). By doing so, remarkable difference between them in 8/10 groups were observed. In these 8 groups, we found an average difference of 3.36 points (in a 0–10 scale) in the final scores between teammates of the pair (group 1 compared with group 2). The average scores obtained for group 1 were 6.52 while only 3.16 was reached for group 2. By following those results, it seems that students (which were free to choose their pair) were arranged in groups with a teammate being much better than the other. However, this remarkable score difference is not detected in the individual written test performed before the teamwork practical sessions, as can be seen in Fig. 5b, where the scores of the two students of each group show an average difference of 1.01. In Fig. 5a, the scores obtained for both groups (black for initial written examination before practical experiment, and grey for final examination) are shown. It is clear that the differences are much higher in the final exam (i.e., after the practical session). It is particularly relevant that the huge differences in the final exam are not related to students that were different at the beginning, since we can find many different scenarios before the practical sessions. For example, students from working groups 4, 5 and 7 even changed their tendency. In those cases, one student from the working group was better at the beginning but got much worse scores in the final examination than their partner. This heterogeneous initial scenario demonstrates that the significant

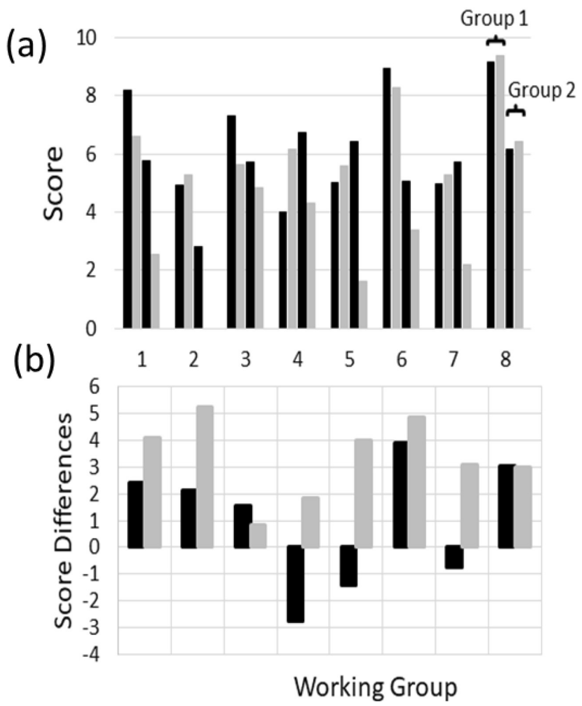

Fig. 5. Scores (a) and score differences (b) of all the students in the 8 groups where a significant effect of the working groups has been detected. Black: Scores from the test done before the practical sessions. Grey: Scores of the final exam.

differences found after the practical sessions should be influenced by something related to the teamwork in this activity (computer assisted practical sessions). However, it is worth noting that this effect is not found in the chemical laboratory teams, formed by three teammates. In this case, the heterogeneous profiles found at the beginning are also found after the experimental sessions.

5. Discussion

It is well-known that many parameters such as motivation, enjoyment [27] or perceived usefulness [28] are factors that strongly influence on students' performance in many different tasks in their learning process. Indeed, this is also happening when analyzing teamwork. An active behavior is also considered an appropriate strategy for improving knowledge acquisition and even teamwork skills [29]. Assuming those premises, we are analyzing the effect of team working and how this kind of activity can change or modify some students' attitudes and how these changes can have a significant influence in their learning efficiency.

It becomes clear that teamwork does not have the same influence in the different teammates. In the case of practical sessions with computers, in 8 of the 10 groups formed, one teammate is positively influenced and the other one is negatively affected. This can be explained bearing in mind the results obtained for individual work (Applied Computer Science), where we observed a better students' performing when they focused on the tasks. In other words, they should be active when using computers or developing their algorithms. In our opinion, the problem detected in the work groups of "Design of Water Treatment Facilities" is that the pair tends to be leaded by one teammate and the other one only "pay attention" to the work done by their partner. This passive attitude has been found to be almost useless in our first analysis (Fig. 3B compared to Fig. 3C). This hypothesis is also supported by the not detected negative effect of work teams in the groups that performed the laboratory activities, where the complexity of the practical work does not allow students to assume a passive attitude, and working as a real team.

In order to maximize the work groups' effectiveness, we suggest being aware in designing team activities in engineering, especially when the activities allow students working individually when they should do it as a team. Wrong strategies can induce huge differences between the involvements of the students conforming a group, due to some teammates tending to lead (obtaining better results) and others simply watching or listening to (being negatively affected in their learning effectiveness).

The experiments developed in this article are related to subjects from the Chemical Engineering grade. However, the kind of activities proposed to students in the laboratories are closely related to many others from different engineering grades. Even in the cases where specific contents are strictly related to Chemical Engineering, the procedure of the experiments and the documents that must be completed usually follows general patterns. For this reason, the results of this article can be also extrapolated to other engineering disciplines.

Although this work can be extended to other disciplines with similar format, it is also limited by the methodology followed in different subjects. It is reasonable to extend our results to subjects where numerical problems are solved. However, in disciplines where the teachers do a subjective assessment, we cannot be sure about the validity of our conclusions. In those cases, different approximations such as the use of rubrics has been proposed to evaluate teamwork activities [30].

6. Conclusions

In this article, we have analyzed the influence of experimental activities in work groups on the final assessment of Chemical Engineering subjects. We have concluded that some tasks are inappropriate to be carried out by a group. We must be aware of group activities' limitations and proposing some experimental activities such as individual tasks. We have realized that, in pair groups, the group's leader-student role benefits the students who assume it, while the listener-student tends to worse its academic performance. These results are also supported by the analysis of practical activities developed individually using adaptive tests, where student's scores are highly correlated with the tasks that students finished focusing on the activity. We can conclude that teamwork can be of great interest, but potential troubles must be considered before planning task developments in groups, to avoid the inadequate academic performance of some students due to a wrong planning. An alternative would be including new subjects focusing on undertaking group projects as part of their course.

Future work should involve the extension of our analysis to other engineering and natural sciences disciplines. In those studies, it will be convenient to evaluate the creation of groups following the findings of this article, as well as comparing students' performance when working in groups or individually.

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