Bringing simulations to the classroom: teachers' perspectives

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Abstract The potential value of simulations in education has been argued already for many years, with the arguments often referring to learning, motivation, or both. However, implementation of educational simulations in classrooms is still lower than what policy makers and researchers would like to see. This study is a continuation of a series of empirical studies where students have investigated the basic principles of electric circuits in a simulation environment in controlled research settings. These studies show positive effects of the simulation both in terms learning outcomes and interest. The present study focuses on the same simulation environment, but changes the focus from students to teachers in regular classrooms. The participants were nine Finnish elementary school teachers that implemented the circuit simulation in their regular classrooms and reflected on their and their students' experiences. The overall picture that emerges is that for most teachers this was a positive experience, but the results also reveal useful pointers and areas of improvement to take into consideration when thinking about bringing simulations to the classroom. Both the positive experiences and the useful pointers will be discussed in the broader framework of bringing simulations to the classroom.

Keywords: Computer simulation, inquiry learning, teacher, learning environment

Introduction

Computer-based simulations, or virtual labs - wherein students use interactive simulation software to conduct hands-on experiments by virtually manipulating virtual equipment and materials - have become an increasingly popular alternative to real equipment in science classrooms. Probably the main reason behind the growing popularity of simulations is their improved usability and availability. Dedicated online repositories such as PhET (phet.colorado.edu) and Go-Lab (golabz.eu) offer hundreds of simulations that can be instantly deployed at school or at home. Modern simulations work directly in an internet browser; to use them, only a PC or mobile device with an internet connection is required. In last spring's pandemic situation simulations - as well as other online resources for learning and teaching - came into exceptional need as schools around the world were forced to switch to distance learning and look for alternatives to traditional instruction.

One of the theoretical background ideas of using simulations and real labs in science education is that learners should have an active role in the learning process (de Jong, 2019). Traditional teacher-led science instruction has been accused of on the one hand not activating, challenging and inspiring pupils sufficiently (Rocard et al., 2007), and on the other hand resulting in inert and disconnected knowledge (Hake, 1998). There is robust evidence showing that students learn better when they have an active role in the learning process and learning is connected to their prior knowledge (Bransford et al., 2000). In this study, we use the concept of inquiry learning to refer to active learning and student-centred pedagogy. A general starting point for inquiry learning is that answers to the tasks or the key laws of the phenomenon under investigation are not directly accessible to learners; instead, learners are encouraged to conduct investigations under teachers' guidance and set-up experiments in the subject matter, in order to seek and find out (or discover) the answers and solutions to the tasks and problems. While conducting the experiments, learners also gain valuable first-hand experience of activities that mimic aspects of scientific research and they develop competences in relation to 21st century skills that have been put forward in major policy documents (e.g. Hazelkorn et al., 2015; Next Generation Science Standards, 2013).

In addition to practical reasons, the use of simulations in science education is supported by the good learning outcomes obtained in research. According to research, the general trend is that learning with simulations results in at least as good (e.g. Klahr et al., 2007; Triona & Klahr, 2003) and sometimes even better (e.g. Chang et al., 2008; Finkelstein et al., 2005; Jaakkola & Nurmi, 2008) learning outcomes than when learning involves real equipment. Learning in a simulation environment would also seem to motivate students (Tapola et al., 2014). It appears that in those studies where simulations have produced better learning outcomes than real equipment, the special features of the simulations have improved learning outcomes. Finkelstein et al. (2005), for example, conducted a study during a university physics course where students studied the basic principles of electric circuits using a simulation or real equipment. Contrary to real circuits, the simulation enabled students to observe continuously the electron flow inside the circuits. The outcome of the study was that the students using the simulation outperformed the students using the real equipment on a conceptual knowledge test administered at the end of the course. According to the authors of the study, the fact that the simulation provided direct perceptual access to the concept of current flow helped students to gain better understanding of the functioning of DC circuits. What is particularly interesting in Finklestein's results is that students that learned with the simulation also succeeded better than the real equipment group in a transfer task where they had to assemble real circuits and explain how those worked. In this context, however, it should be emphasized that the primary learning objective with simulations is a conceptual understanding of the phenomenon under investigation and not, for example, the learning of practical laboratory skills. It is also important to understand that the way how learners make the discoveries in a simulation environment is fundamentally different from how scientists initially discovered these things (e.g. electron flow is not directly observable in any lab) (Steinberg, 2000).

In previous studies on educational simulations, the main focus has been on students and their learning outcomes, which is well justified as the main aim is to develop instructional methods and learning environments that promote learning and engage students. In these studies a researcher typically acts as a teacher with the aim of having more control of the impact of individual teacher on the results of the experiment, thus leaving the real teacher outside of the research context. Because it is ultimately the teacher that decides whether or not to use simulations in the classroom and who will be responsible for the implementation, it is also important to consider their views as this may provide insights that may also benefit designers. Therefore the main focus in the current study was on teachers' perspectives and experiences related to the implementation of a simulation learning environment in their classroom.

1. The Present Study

The present study was carried out in Finland as part of a European project aiming to advance inquiry-based science education in schools across Europe. For this, a training course was developed and organized for teachers to improve their knowledge base in inquiry learning and to provide them with hands-on experiences of inquiry learning. As part of the training course, the teachers' task was to implement three distinct inquiry lessons with their pupils. This paper focuses on teachers' experiences from the first inquiry lesson that was implemented using a simulation learning environment.

A training session was held for teachers about a week before the simulation lesson. Presented training materials were shared with teachers at the end of the session, to allow teachers to study the materials at their own pace to prepare for the upcoming lesson. At the beginning of the training session, teachers were told about the theoretical starting points of inquiry learning and introduced to the Pedaste et al. (2015) model of inquiry learning. The model conceptualizes inquiry learning as a cyclical process that consists of five interconnected phases. The model starts with the Orientation phase that introduces the topic and aims of the study to stimulate learners' curiosity. In the Conceptualization phase learners state hypotheses and/or research questions, which should guide their actions in the following Investigation phase when learners gather empirical evidence and conduct experiments to answer the research questions. In the Conclusion phase findings from the Investigation phase are interpreted and summarized. The Discussion phase is directly connected to all the other phases and is thus an integral part of the whole inquiry cycle. At the end of the inquiry cycle Discussion refers to communicating the outcomes of the study to outside parties (e.g. peers) and to reflecting on the overall inquiry processes. The inquiry learning model was presented to teachers to help them to see the process of inquiry learning as a continuous process that consists of different phases.

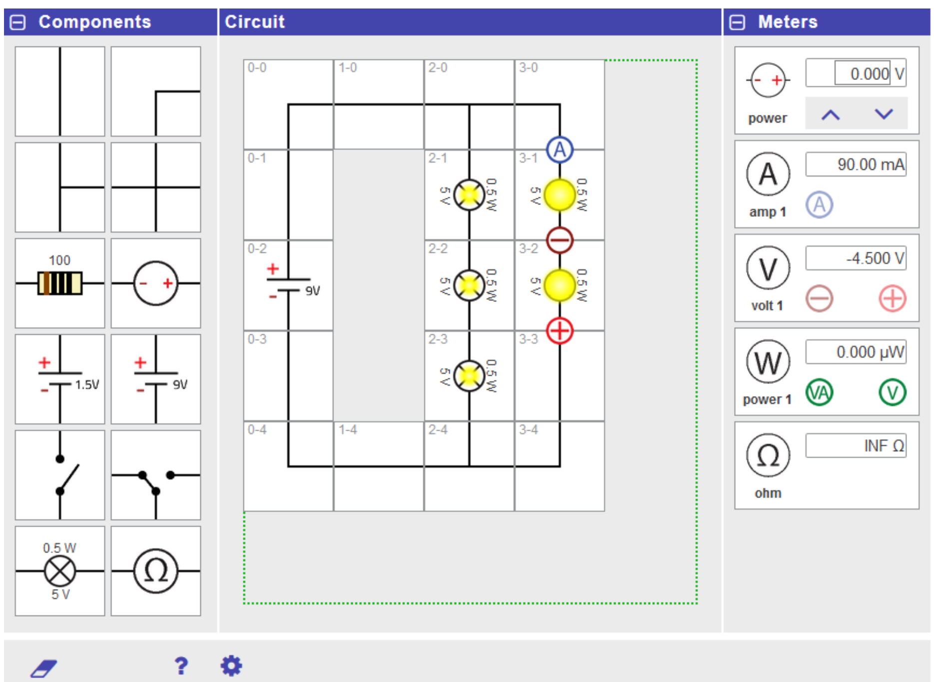
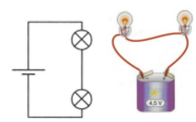


Fig 1. The circuit simulation (https://www.golabz.eu/lab/electrical-circuit-lab).

Next, the teachers were introduced to the simulation and related worksheets to be used in the upcoming lesson. It was a circuit simulation (Figure 1) that allows students to learn about electric circuits by building circuits, conducting electrical measurements (e.g. potential difference across bulbs) and observing circuit behavior (e.g. the brightness of bulbs). The simulation is a HTML5 application that works on any modern web browser, both on PC and mobile. As can be seen in the figure, the representation level of the simulation is semi-realistic: the circuit layout is schematic but the brightness of the bulbs changes dynamically based on the circuit configuration. The simulated model is authentic except that the wires have no resistance and the battery is ideal (i.e. it always remains fully charged).

a) WITHOUT COMPUTER Predict what happens to the brightness of the bulbs if a second bulb is added to the previous circuit as illustraded in the nearby pictures (2 bulbs in series). Check if you agree

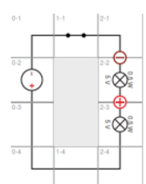
- ☐ There is no change in the brightness of the bulbs
- ☐ The bulbs become brighter
- ☐ The bulbs become dimmer
- ☐ The upper bulb is brighter than the lower bulb



b) WITH COMPUTER Test your prediction by constructing the circuit with the computer. What do you notice (check if you agree)?

- ☐ There is no change in the brightness of the bulbs
- ☐ The bulbs become brighter
- ☐ The bulbs become dimmer
- ☐ The upper bulb is brighter than the lower bulb

c) WITH COMPUTER Measure the voltage of the upper bulb of the circuit with the voltage meter as instructed in the nearby picture The voltage of the upper bulb is ________ volts.



d) WITH COMPUTER Now, measure the voltage of the lower bulb. The voltage of the lower bulb is___volts.

e) What can you say about the voltages of the two bulbs?

☐ The voltages are the same ☐ The voltages are different

What can you conclude about the bulb voltages in comparison to the voltage of the battery in a two-bulb series circuit (check if you agree with a statement)?

- ☐ The voltage of a single bulb and the voltage of the battery are the same
- ☐ The voltage of a single bulb is half of the voltage of the battery
- ☐ The voltage of the battery is divided equally between both bulbs
- ☐ The total voltage of two bulbs is equal to the voltage of the battery
- ☐ The total voltage of two bulbs is half of the voltage of the battery
- ☐ The total voltage of two bulbs is two times the voltage of the battery

Fig 2. Example worksheet with instructional support.

The worksheets scaffold students' inquiry process with the simulation. There are nine worksheets in total that progressively become more difficult (more complex circuits) and open-ended (less support). However, the basic structure of the worksheets is the same, and together they create many small inquiry cycles as can be seen in the worksheet example in Figure 2. To activate students' prior conceptions, they are asked to predict circuit behavior before actually building the circuit with the simulation. This corresponds to the Conceptualization phase in Pedaste's (2015) model, which is then followed by the Investigation phase when students build the circuit and conduct requested measurements. At the end of the worksheets, students are asked to summarize their findings (Conclusions phase). The Orientation and Discussion phases are also part of the activity (but not explicitly part of the worksheets): in the beginning of lesson teacher introduces the topic and demonstrates the basic functioning of the simulation, and as pupils work in pairs throughout the lesson, this means that the Discussion phase is an integral part of each worksheet. The teacher mainly monitors the work of the pairs and helps them when needed.

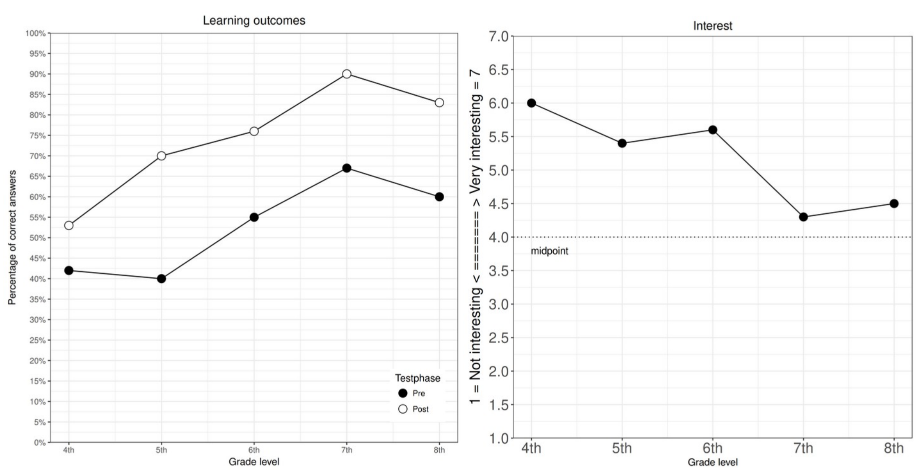


Fig 3. Trends in learning outcomes (pre- and post-) and interest across grades from the experimental studies.

The above worksheets and corresponding simulation have been tested previously with upper elementary and lower secondary students (e.g. Jaakkola, Nurmi, & Veermans, 2011; Jaakkola & Veermans, 2015; 2018, 2020; Veermans & Jaakkola, 2019). The outcomes of these studies have been largely positive: as can be seen in Figure 3, the simulation was able to improve students' understanding of electric circuits over a range of 5 grades (4th-8th; 9-15 years) and students' interest levels were from above average to high, though there seemed no clear relation between the level of interest and learning outcomes and/or learning gains. In the present study we wanted move the focus from students to teachers and investigate how teachers perceive the simulation activity after they have implemented it in their classroom.

For this purpose teachers (N = 9) were asked to complete a questionnaire after the simulation activity. The questionnaire consisted of 16 semi-structured questions that were organized along three broad themes: thoughts and expectations prior to the implementation of the simulation activity, experiences during the implementation and the connection of the activity with the inquiry model. The analysis uses a combined deductive and inductive framework (Kyngas & Elo, 2008) where the answers to these questions will first be analyzed deductively following these three themes and their respective questions followed by a discussion that highlights themes that arise inductively from this analysis.

2. Analysis and Results

One of the first things that becomes clear from the answers to the questions is that there is no two teachers or classrooms that are the same. On practically all questions there was variety in the thoughts and experiences that the teachers shared.

3.1 Before the implementation

The first questions tapped into the ideas that teachers had before the actual implementation of the simulation lesson. Probably because teachers did not know what questions would follow some of the answers also already contained references to the actual implementation. The first question asked the teachers how they saw teaching electricity circuits (easy or challenging). Most teachers said that they see it as challenging with arguments that refer to themselves (own knowledge is weak), the students (it may feel distant for students), or resources (we don't have proper equipment). Two teachers said it is both easy and challenging and only one considered the topic easy. The next question asked the teachers about their first impressions of the worksheets that accompanied the simulation. Again there was a variety in the answers of the teachers with some teachers leaning more towards calling them clear -one teacher calling them clear, one clear but sometimes with a lot of reading (adding that students don't always do), one interesting, one that they looked difficult but turned out to be well structured- and some seeing them as challenging or difficult with one teacher referring to them as challenging and another as messy and difficult. On the question whether they felt the instructions in the worksheets were clear several teachers said that they thought so themselves, but sometimes adding some disclaimers from what they saw in the classroom during the implementation, like students having difficulty with the measurements, that careful reading was required, that some had quite a bit of text and could maybe have been ‘cut’ up into smaller units, that this need for careful reading and the amount of reading gave difficulties for 2nd language students, but also that they became less self-explanatory towards the end, and that that was a good thing because it made that students needed to ‘know’ things from before. Their impression of the simulation itself was the one of the few things where the teachers generally agreed, with 6 teachers expressing very positive comments adding notions like easy, motivating, interesting, and fun. The next question about the objectives again brought much more diversity and also illustrates the general ‘dilemma’ of inquiry being about the content or the process. Four teachers explicitly referred to learning something about electricity, thus focusing on the content in their answer. Two referred both the process and the content with one referring to it as students daring to try out themselves and being able to follow the worksheet instructions without continuous guidance from the teacher and hoping that this would bring understanding about electric circuits. Other teachers focused on the process, for example referring to doing inquiry together or that everyone is able to do the tasks. An exception was one teacher that did not refer to content or process, but only to the role of the teacher and that this had not been clear beforehand and only became clear afterwards. Interesting was also to see that some teachers mentioned to have spent less time preparing for the lesson than for a normal lesson (which one said was not such a good idea), some about equal, and some that they had spent more time because they had gone thoroughly through the whole process themselves. When asked about their expectations for the implementation itself, two teachers were expecting that it would go nicely and one said not to have had any expectations beforehand. Other teachers had some reservations, for instance that their students were not going to be following the instruction, another that the students would not understand the instructions and would be afraid to start trying (as they had not often done these kind of activities), one thought the tasks would be hard for the students but they turned out not to be, and one thought giving students guidance would logistically be a problem but that turned out to be compensated by students working in pairs and helping each other, thus off-loading some of the work from the teacher.

3.2 During the implementation

The next set of questions asked the teacher about experiences during the implementation. The clearest consensus was on the question related to the simulation itself. Only one teacher mentioned some issue but still said the simulation worked well. One teacher had apparently used both computer and tablet and mentioned that it worked even nicer on the tablet because things could be dragged and dropped with the fingers. When asked whether the worksheets worked as they had anticipated many teacher referred to the active attitude of the students during the implementation. This was however paired with different remarks: it went well, students were trying out and testing things, in the beginning there were a lot of questions, I needed to guide more than expected because students were not reading instructions and just started doing things, and the pair work did not result in the depth of discussions that I had hoped for. Regarding the pedagogical virtue of using the simulation in the classroom four teachers answers were very brief (two excellent, one really good and one ok). The others were more elaborate and three of these teachers explicitly referred to real equipment, but while one said it made it clearer than working with real equipment, the other two had some doubt about the connection between simulation and real equipment. One wasn't sure if students would be able to do this also with real equipment but also stressed that the affordances of the simulation triggered enthusiasm in learning, the other wasn't sure about transfer to real either, but thought that demonstrating them the real equipment shortly beforehand would help to make the connection between simulation and reality. One teacher noticed differentiation within the classroom with some really learning and others just progressing through the tasks without acquiring in depth knowledge. Teachers were also asked what aspects they liked in the material, and if there would be things that could be improved. One teacher answered this question with just "to be able to use it" referring to the intention to use the activity also in the future. Several others referred to motivation and the eagerness in students as the best parts. Other good things that were mentioned were the brightness of the bulbs, and quick and easy measurements, being able to try things out, and clear self-contained worksheets. Related to things that could be improved, one of the teachers mentioned that the worksheets could have benefited from clearer, shorter sentences (a similar remark was made by another teacher in relation to 2nd language and special needs children) and sometimes the relation between pictures and text was not clear. One of the teachers missed some kind of feedback for students so they could see if they are on the right track or alternatively monitor the students by checking the answers before students would move on to the next task could also be an option (but wasn't sure how that could be arranged). The final question in this section addressed potential improvement of the material in terms of supporting teachers. This elicited some general remarks (to know these resources exist, to have/take time for these kind of activities), and some more specific like a kind of manual or glossary that explained all simulation elements, an "answer key", proper instruction and manual for teachers and suggesting teachers to emphasize to the students that they should follow the instructions on the worksheets.

3.3 Connection with the inquiry model

The last set of questions asked teachers to reflect on the implementation in relation to the five phases of the Pedaste et al. (2015) model that was introduced to them during the training. For the question which aspect in the model was realized most successfully, most teachers mentioned investigation, often in connection with telling that the students were really engaged and the self-directed nature of the activity. Three teachers also mentioned the conclusion, and one the discussions that students had in the process. These discussions were mentioned by four teachers as something that did not work that well. Reasons mentioned were time constraints and difficulties of students with discussing. Three teachers mentioned the orientation, in one case this came from the (mis)understanding of how to use material and in the other it was a deliberate choice to use as much time in the computer classroom for the investigation as possible. The final question asked if they thought this activity gave a good experience with the inquiry model. Most teachers answered positively to this question, but in some cases also added comments on how this could be even improved with two teachers mentioning that going over the entire cycle in class could have brought it even closer to a real inquiry, and one that for second language learners going over the "concepts" could have improved the experience. One teacher mentioned some students had "missed" real equipment, and one that it had not worked out well.

3. Discussion & Conclusion

On the whole, experiences from the teaching experiment were positive and according to the reports of the teachers the implementation of the simulation in the classroom had encouraging effects on both teachers and students in most cases. It was interesting and positive to see that teachers were mentioning many of the arguments that have been put forward in the literature. Almost all teachers referred to the learner-centric nature of the learning environment. Teachers also explicitly referred to affordances of the simulation (e.g. being clearer than real equipment and getting clear and quick measurement results) (e.g. Wieman et al., 2008). It was also clear from the experiences of most of the teachers that they appreciated the effect that the learning environment had on their students' interest and engagement (cf. Tapola et al., 2014). Many explicitly mentioned the fact that the learning environment was motivating and engaging and that the students liked being able to explore with the simulation in their answers on more than one occasion. Learning outcomes were not explicitly measured in this study and in fact some of the teachers had some doubts whether sufficient understanding had been obtained by all students, or would transfer to understanding of circuits in the real world. As discussed earlier, learning outcomes in our earlier experimental studies suggest they do, but it would of course be good to affirm that also in a real classroom setting in future studies.

One of the generally positive things that came up through the comments of the teachers is that most of them clearly recognized that simulation based inquiry learning emphasizes different aspects of learning (cf. de Jong, 2019). Teachers for instance appreciated that they saw some students collaborating really well, but also that some others were not able to collaborate fruitfully, seeing this as something to develop. As mentioned before teachers emphasized the engagement of their students, and the fact that students were daring and being able to try out and test things, but some teachers also expressed concern that maybe not everyone learned to the same extent, for instance because, as one teacher mentioned, some students were progressing through the worksheets without proper understanding of the material they covered. It is interesting that these concerns were raised here (they have also been raised in relation the online teaching because of COVID-19) while that is something that is not often discussed in the context of regular instruction, even though it is clear that differences between pupils' performance also exist in that context. Therefore, an interesting question for future research is if that is because these differences are indeed more pronounced in these kind of inquiry learning settings when learners need to take more control of and active role in their learning, or because teachers' pay more attention to these kind of things when they try out new things (although all teachers involved in the study reported having previous experiences and perceptions of inquiry learning, it became clear during the training that the teachers generally used and were more comfortable with more teacher-centric methods in their teaching).

The observations and suggestions for improvement of the learning environment and teachers' own implementation show that most teachers in this study are in principle able to make material their own and adapt it to the needs of their classroom. This is positive and important, because one of the clear messages from this study is that it is virtually impossible to design a learning environment that can be used out of box or is perceived the same by all teachers; the same learning environment that was seen as very clear and working flawlessly by some teachers was assessed more critically by others. In addition, teachers also indicated different learning goals for their implementation: some emphasizing the process, others the knowledge outcomes and some both. This emphasizes the important role of teachers in relation to implementation of simulations in the classroom, or any other addition to the regular classroom repertoire. It requires their involvement, their understanding of the affordances and the pedagogical goals that they try to achieve. This is not trivial (see also: reference to Papaeviadrou chapter) as was also illustrated by the expectations that teachers had beforehand. These clearly indicated that it is not always easy for teachers to estimate how things will go even when it concerns the students in their own class.

Of course teachers also mentioned things that could have been improved, and some of these would even be fairly easy to achieve. However, in light of the discussion above, rather than trying to incorporate all possible suggestions for improvement, it may be more important to support teachers' own agency in adapting the learning material to their own classroom (Ketelaar et al., 2012). In that case it may be enough to provide teachers with learning material that can in itself provide a positive experience and the results of this study showed that for the majority of the teachers implementing this simulation based learning environment had indeed been a positive experience. In combination with their recognition of the potential of these kind of interactive environments in their classroom and explicit intention to use this kind of material more often, the fact that they saw opportunities for improvement could be seen as a positive outcome. The more complicated question is of course how to engage teachers in training and implementation experiences. One potentially fruitful approach would be to create positive experiences during the teacher training. Chapter (Penn chapter) in this volume presents an example of the positive effects of such experience. Combining these experiences with an inquiry model as was done in this study may also be important, as it provides teachers with an interpretation (and evaluation) framework, and as one teacher indicated introducing such framework to students may also be a useful addition to their learning experience.

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