

LONDON JOURNAL OF INTERDISCIPLINARY SCIENCES

eISSN 3049-7809

Modeling frustration trajectories and problem-solving behaviors in adaptive learning environments for introductory computer science

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Abstract

Frustration, an inherent part of the classroom, is routinely associated with negative stigmas, however, if appropriately managed it can be a highly effective tool for excelling students. Often referred to as eustress, it is the principle that follows the premise of introducing students to a topic they are not familiar with, causing frustration as they learn the currently unfamiliar topic. In the experiment, a correlating pattern involving behavior can properly monitor frustration in a way that remains productive for the student. This process can be emulated using artificial intelligence in schools (AIED) to create adaptive algorithms that provide students with unfamiliar topics until the point that said student becomes sufficiently frustrated, at which point the AI would slow down the curriculum. Through discernment patterns in learners' frustration levels and problem-solving strategies, AI can dynamically adjust the difficulty of tasks to accommodate each student's personal needs, as well as the pacing of instruction, and the provision of support. In doing so, AIED could mitigate the adverse effects of extreme frustration and reap the benefits of frustration that pushes a student to a further level than our current educational system can provide. With AIED creating the ideal structure of adaptive scaffolded learning, students' needs can be individually fostered in a way that most preferably suits them. This ability to push students into learning curriculum at such an intricate level will allow students to further develop their independence when solving future problems as the high difficulty will authenticate the student's ability to grasp the concept extensively. The intricate interplay between AIED and frustration models is crucial for advancing the frontiers of human knowledge and pushing students to achieve their full potential.

Keywords: Artificial Intelligence in Education (AIED), Adaptive Individualized Curriculum, Frustration models, Scaffolded learning, Positive affect



 <https://doi.org/10.31039/ljis.2024.2.227>

London Journal of Interdisciplinary Sciences, 2024-2



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Introduction

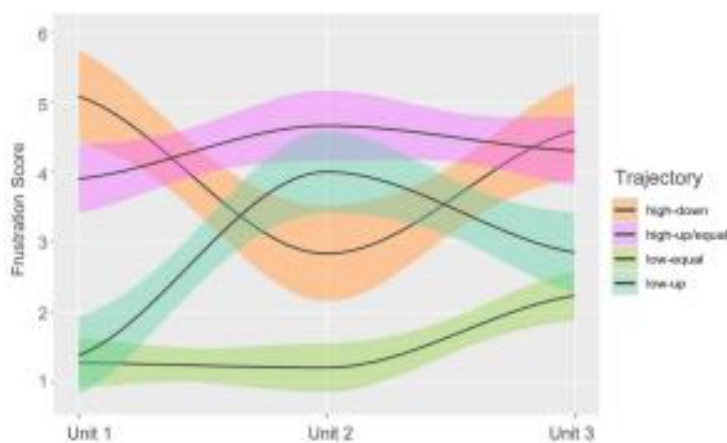
In coeval education systems, the use of AIED has sparked rampant interest and debate worldwide. With many advocating for its endless possibilities of expanding the average classroom, even to those in lower economic situations, the fears society still upholds must be taken into consideration. The ethical implications and societal ramifications of letting computers take over more of our daily lives are still important topics to discuss. Many of the primary points aimed against AIED include job displacement, data/ privacy concerns, and the possible opportunities for kids to be propagandized. Moreover, critics argue that the overreliance on AIED may result in a lack of critical thinking skills, and interpersonal relationships between peers and teachers, and may remove students even further from the classroom. However, using AI-powered education can benefit the classroom in ways that would be inaccessible in a modern classroom. With AI, students can complete highly personalized schoolwork online that is designed by the computer to come to the brinkmanship of a student's knowledge, causing induced frustration. Applying such a principle will ensure students are being adequately challenged within the school curriculum, pushing them to a greater degree than before. While many educators strive to integrate pedagogical methods of learning throughout the classroom, meeting each student's individual needs has proven to be nearly impossible, especially in larger classrooms. Adapting to the specific needs and prerequisites of a student's education can be not only inefficient to the classroom as a whole but entirely too demanding for teachers. To meet the diverse plethora of needs of students while applying the principles of scaffolding, though beneficial, is just not possible in our current education system. However, with the advent of AIED, the opportunity to reshape individual catering to fit each student's needs becomes a possibility. The opportunity to create an adaptive program of education that applies the image of scaffolding within the educational landscape is now becoming a readily available option to shift students' affect within the classroom. Exploring the potential plethora of benefits employed by AIED-driven scaffolding, particularly through the lens of positively implemented scaffolding dependent on the effect of a student's engagement and frustration, can foster enhanced learning to create higher rates of succession in class is a rising possibility. The experiment for discussion was designed to test and predict frustration graphs and how the integration of help provided to students, can establish a harder curriculum crafted by AIED, and how it will personally cater to intentionally creating initial frustration to challenge the students past the normal point done within the modern school system. By delving into the theoretical paradigms of scaffolding and the psychology of frustration, the study aims to elucidate how AIED can be harnessed as a powerful tool to optimize learning experiences, catering to individualized needs while promoting cognitive growth and resilience in learners. This paper's purpose is to provide a summary of the rationale overview for integrating artificial intelligence AIED within our modern school systems, specifically through the medium of online curriculum as discussed during X. Tian's. The focal outline emphasizes the importance of adapting frustration levels within students and the possible improvements of adaptive curriculum that may accommodate each student individually for said student to be sufficiently challenged while remaining particularly motivated within the classroom. The objective overview of the experiment was comprised of the following two questions formulated by X. Tian: "1) What common trajectories of frustration arise over problem-solving interactions with a block-based programming environment? 2) Do students with different frustration trajectories display



different problem-solving behaviors?” (Tian et al., 2021). Throughout the experiment, productive frustration was used as a catalyst to promote student growth, as they were being pushed to their peak allostatic load by the curriculum in a way that kept students engaged. Four distinctive models of frustration were identified throughout the 86 undergraduate students of computer science. Finding the equilibrium between disengagement and progressive learning is a vital statistic to understand when causing induced frustration. During the course of the experiment, of the 86 students, 67.4% ended up majoring in computer science. Frustration models created and monitored by AI can help predict and guide students through their time within the education system to ensure they are sufficiently challenged without becoming disengaged from the content being provided. This level of intense education would be beneficial as just about any student with availability to a school computer would be able to approach this means of education allowing for equal access to education throughout the economic classes.

Background, Method, Subjects

In the experiment the proctor, X. Tian, consistently references the following model, we will refer to it as *Model B*. This chart represents the core findings from the experiment. The four individual line graphs represent a separate statistic and category of the students. Throughout the experiment, 86 computer science students were participants over three units. With 20 programs laid out throughout the three units, we see an average of 6-7 activities that take about an hour to complete, throughout each of them. The students in this computer science program were provided with a curriculum known as a block-based programming environment. A help button was provided to the students in case of a dilemma, to ensure students do not become stymied during the activities. Throughout the experiment when students used this hint button it was referred to as help-seeking. Another form of student interaction within the website was known as workspace exploration, in which the material is



b.

explained to the students. With the main premise of the course being the levels of frustration within the curriculum and how it affects students, their experiment was provided with a questionnaire to properly reflect the students perceived level of frustration. This was accommodated by adding a seven-item Likert questionnaire at the end of each unit the students completed. The Likert system is a form of questionnaire that gives the students a spectrum to choose

from for questions that were provided such as, “I was frustrated while working on this unit.” Keeping this in mind X. Tian was able to establish, and form results off on the student’s level

of frustration, how it affected the performance/ completion of the activities, and lastly how the number of hints used correlated with the pattern of frustration.

Results Answering RQ1

Referencing *Model B*, from the 86 students present during the experiment four distinctive models became readily apparent. These four clusters were created through the establishment of k-medoids that would agglomerate the learners' level of frustration collected from the Likert system. To visually represent the frustration onto an interpretable graph, distortion elbows were made use of. With a clear division between the students, 36 began unit 1 with low levels of frustration within the ranges of $[1.20 < x < 1.4]$; the other 50 students started unit 1 with high levels of frustration within the ranges of $[4.40 < x < 5.10x]$. Of the four clusters identified, the trends were named off on the direction of progress based on frustration, (High-down, 12), (High-up/equal, 24), (low-equal, 29), (low-up, 21). Throughout the units, a mean average of 3.18 out of 7 was ranked across the frustration scale. Following the first experimental question, numerous patterns can be taken into account. 74 out of 86 students experience higher levels of frustration towards the end than they started with, meaning students of this category are leaving more frustrated than they started. Another common trend is that students who start with higher levels of frustration end with higher levels, whereas those with lower levels end at lower levels. This is important when taking into consideration that the curriculum would be best for students if it initiates at an easier level and quickly builds up into harder course material. Many students need to be introduced to a topic in a way that entices them to naturally gravitate toward the subject and learn the basics. For students whose frustration increased throughout the units, this rise predominantly occurred after unit 1 with a mean rise of 2.71, 3.29 after unit 2, and 3.52 after unit 3. The rise of frustration from 2.71 to 3.29 is a rise of .58. However, the rise from 3.29 to 3.52 is by .23. Overall, the shift from unit one to two is nearly increased by twice the amount compared from unit two to three.

Results Answering RQ2

With the main question at play being the intricate interplay of workspace exploration in addition to help-seeking to depict current and future frustration graphs, a correlation between the two factors becomes present during Dr. X. Tian's experiment. To consider this variable a one-way MANCOVA was used to articulate a correlation between workspace exploration and/or help-seeking to student behavior according to the frustration graph. At this point a substantial statistic was shown with, $(F(18, 209.789) = 2.491, p = .001, \text{Wilks' } \Delta = .578, \text{partial } \eta^2 = .167)$. The statistics provided are not complete, however manage to depict patterns in the student's behavior. Low-equal students, as explained, had completed the work with a low number of workspace exploration and help-seeking throughout the course. Low-up students presented with $(M(SD) = 0.64(0.99))$ during unit two; this establishes them as the highest uses of workspace exploration during unit two, the unit in which their frustration was noted with a substantially significant increase. The high-down group showed the most abnormal behavior from the students in which they frequently used help-seeking throughout all three units instead of just one unit like the rest of the participants. With the results being



(M(SD)units 1,2,3= (0.74), 0.81(1.84), 0.22(1.84), this group had not only used more hints than all three other groups in unit 2 but had used more hints than the two low groups throughout unit 1. Lastly, the high-up group had the following statistics for workspace exploration (M(SD)units 1,2,3= 0.26(1.32), -0.55(1.05), -0.45(0.87)). Even though conducting an average amount of workspace exploration in unit 1, they had the least amount of workspace exploration done in units 2 and 3. They even had a substantially lower amount of workspace exploration than the low-up group in Unit 2 and the low-equal group in Unit 3. Even the division between a cluster of participants using more help-seeking or workspace exploration gives us future insight into the psychology and predictability of the students in a way that can be beneficial to further structuring a classroom's curriculum.

Result Discussion Answering RQ1 And RQ2

Modeling the experiment throughout different courses in college with ranging difficulty than computer science would add an abundance of information based on learning and frustration. The different types of students show a wide range of prerequisite knowledge as some students start unit 1 with nearly five times as much frustration than others, this alone shows the difference between the student's confidence and knowledge of the classroom just starting. With student clusters such as the low-equal group, it's plausible to assume these students are already familiar with the course's information as they remain the least frustrated while still maintaining relatively low rates of help-seeking and/or workspace exploration. Low-up initially presents the same as low-equal in terms of frustration, however, the confidence of these students quickly backfires as a drastic spike in frustration during unit 2 as well as the amount of workspace exploration, most likely due to them not properly paying attention to the material in unit 1 and making up for their lack of knowledge in unit 2. A drastic increase in help-seeking and workspace exploration where there wasn't before can indicate previous disengagement, causing the compensation to occur later. With the high-up, we see the inception of average workspace exploration during unit 1, however, during units 2 and 3 the workspace exploration radically subsides. Once more the sudden halt in the student's previous activity seeking typically inclines a shift in disengagement. If a student previously had high amounts of help-seeking and workspace activities but no longer does while maintaining a constant state of frustration this could indicate the beginnings of disengagement, such as seen with low-up students. On the other hand, low levels of help-seeking as well as workspace exploration that drastically increase in a short increment of time would indicate previous disengagement, such as described with the 24 high-up students. Overall low levels of workspace interactions would not indicate low levels of engagement as it could simply mean the student is progressing easily through the assigned material as shown within the 29 low-equal students. An algorithm can be set into place to determine current engagement based on patterns of previous frustration and interactions with the curriculum (help-seeking and workspace exploration). Another question that should be taken into consideration is to what extent should students become frustrated to maximize performance in the classroom. Understanding the psychology behind orchestrating frustration amongst students is vital, classrooms that are simply too easy will leave a student bored. In such a state they are no longer being introduced to new content as well as the fact that many students report feeling lost within the classroom as more trials of methodical guessing occurs, typically referred to as gaming behaviors (Baker, 2010: 223). The phenomena of gaming behaviors is depicted as a



student's disengagement with the material due to lack of understanding resulting in students who strategically guess answers based on patterns from other problems rather than understanding the given material. This pattern emerged specifically amongst the 12 high-down students, as they were the main category that used help-seeking over the workspace exploration throughout the experiment. During unit 2, the unit where the frustration drastically decreased, coincidentally is the unit where they used the most help-seeking. From this we can assume the help-seeking was used to compensate for the gap of knowledge that had not yet acquired, allowing them to continue throughout the activities by gaming behaviors, as shown later, towards unit 3, their frustration levels did not only jump back up, but also remain the highest out of the other three groups. Creating a solution to gaming behaviors will cause a shift in the difficulty of the work. However, class work that is simply too hard will cause students high amounts of frustration that cannot be resolved leading to a similar problem of gaming behaviors (Baker, 2008: 33). Formulating an archetypal balance of induced frustration for students is paramount for the future of our education system to mitigate the risk of fostering gaming behaviors amidst students. Reaping the benefits of controllably high levels of frustration in optimal conditions may revitalize cognitive engagement as well as foster critical thinking. However, in suboptimal situations, high frustrations may result in detrimental outcomes such as disengagement, and once more restoring the game behaviors instead of actively participating in understanding the core concepts of a given course, in which case this can dull active learning. Therefore, for educators and future AIEDs, it is imperative that the classroom is designed to implement mechanisms that dynamically accommodate the student's participation and frustration. Individual profiles for each student should be established to properly employ adaptive algorithms based upon the shifting paradigm of individualized education sourced from AIED, as the effects of such a learning style are too beneficial to ignore (Danneker, 2009, Abstract).

Taking such an approach would not only minimize the occurrence of gaming behaviors but also contribute to the maximization of an optimal learning environment where students remain appropriately challenged and motivated while attentive. Additionally, by integrating feedback loops that monitor the real-time analytics, proctors will remain available to calibrate the level of induced frustration, producing the marksmanship of a fine-tuned balance in education without the associated risk of gaming behaviors. Establishing AIEDs to take notice of students' patterns in terms of help-seeking or overall interactions and calibrate the work being given in order to keep students in an optimal learning environment. Fostering genuine engagement through adaptive individualized AIED will ensure students get the most out of their classrooms. (D'Mello, 2012, abstract) D'Mello delves further into enhancing the classroom, through the understanding of a student's psychology through affective states, specifically a student's ability to enter into a state of flow. Affect, responsible for attitudes, motivations, and incorporating emotions, is crucial in the role of shaping education within students. Incorporating education that allows students to be sufficiently challenged while addressing students' emotional states that foster positive attitudes is optimal. In essence, affect influences a student's engagement, attention, and memory, thereby impacting the quality of time and effort the students will spend within a classroom. Examples of students who harbor positive affective states will appear in the form of interest, curiosity, and enthusiasm towards subjects. Such states are far more likely to exhibit higher cognitive patterns of learning. Simply put, students who are interested will be able to spend more effort. To further



understand D’Mello’s research we have to discuss the theory of students entering into a state of flow. This state of flow is a positive affective state that warrants students into dynamic, yet rigorously intense states of thought, a very crucial part for children to experience to progress further within their education. While flow states orchestrate profound states of consciousness, engagement, and problem thinking, they can be broken if an error or misunderstanding were to occur. In cases where errors occur, students in such flow states may often quickly resolve such errors, learning and adapting properly to ensure proper continuation of the curriculum. In circumstances where a student experiences minimal frustration but is shown a method to go about dealing with such errors many times the flow state will continue, if not further increasing the intensity of such a state. On the other hand, students who reach frustration within a flow state and are not opted into a method of solving the work will quickly break out of such a flow state. In cases where the flow state is broken in such a manner, students will often become disengaged or bored. This once more brings in the importance of an AIED that can properly detect students’ affective states within a classroom to keep them properly engaged. The importance of outside factors is also vital when taking into consideration the needed aspects of a classroom for students to enter into flow states, such as positive peers, and teachers. In the occurrence of an environment where students can appropriately engage with one another in positive and respectful manners, creates a supportive learning community and fosters collaboration, communication, and critical thinking skills (Hagener, 1998, 67). Deficiencies in one student may be compensated within their peers allowing for an advancement in learning compared to doing so separately. Establishing an open atmosphere for a positive community throughout classrooms will ensure all students are participating. Students who are more connected to their peers are more likely to actively participate and contribute to classroom activities, ask questions, or seek help. The sense of belonging can lead to increased effect within the students interpersonally and as a collective majority. Cases where students actively engage will encourage growth among their peers. Furthermore, peer interactions may increase positive aspects of affective states through collaboration or ideas. Students will provide diversity in perspective as well as principles, which may spark deeper comprehension amongst other students. Overall, it is imperative for educators to promote and establish positive peer interactions in order to establish a classroom environment that is conducive to learning and growth. In cases where the classroom environment and curriculum are both optimal for a student’s needs, then a higher level of affective states will be reached within students. The sheer importance that affects displays in the learning environment is not properly addressed within our modern school system, as its role is multifaceted. Focus on affect within students would drastically improve motivation, engagement, and academic achievement. Through understanding the fundamental interconnectedness of affect and cognition, proctors can adopt a holistic approach to teaching and learning that fully optimizes the cultivation of positive affective experiences, as well as the nurturing of students’ socio-emotional development. By addressing the affective dimensions of education, teachers can empower students to become lifelong learners who are intrinsically motivated, resilient, and equipped with the emotional intelligence necessary to navigate the complexities of the modern world.



Conclusion

When taking into consideration the information gathered within the sources and the conducted experiment the patterns of students' behaviors are heavily affected by the variables present within the classroom, specifically that of help-seeking and workspace exploration. The frequency of help that students receive in a classroom often depicts the manner in which they will use their problem-solving skills to properly learn from the given problem in order to create solutions. This is specifically in reference to the duration and intensity of frustration levels that students experience in direct relation to a student's affect. This correlates with the pattern of high frustration levels meaning less affect due to students not grasping the concepts of the material causing said high levels of frustration. On the other hand, students with lower levels of frustration will be more likely to enter into states of flow due to positive affect levels. One of the most fundamental aspects for a teacher or AIED to take notice of is the initial patterns of help-seeking or workshop exploration within students. Students who initially engage in both but drastically stop can typically indicate disengagement with the material. The same assumption applies to students who drastically increase in those forms of engagement with the material compared to the initial amounts. These changes in student behavior show that the curriculum given needs to be changed in order to keep students in positive affect states. Scaffolding in education is a priority as it continuously pushes students into unknown material in order to further establish critical thinking and problem-solving skills. While this is effective, students who cannot properly accommodate to the rapidly changing environment will be pushed into negative states of effect further distancing themselves from optimal learning conditions. After a student has reached the point of induced frustration, showing that the work is sufficiently pushing the student, the educator should give shorter problems that are easier to work out. Doing so will further engrain the patterns of problem-solving within the students as they will continuously proceed after solving these easier problems. Simultaneously making the student solve these problems on their own, while not making the difficulty as high, will be the optimal balance for the implication of scaffolding. This premise follows Baker's belief that shorter problems lead to less frustration as well as reduced rates of negative affective states (Baker et al., 2010). The requisition of Deborah's theory is that allowing peer interaction as a means to diversify thought patterns, could also be an effective method for students to become more familiar with the curriculum. Both of these methods would accommodate higher levels of effect while implicating scaffolding. The modern institutions of these programs are already in effect through websites such as *Aleks*, *Conmigo*, *Quizlet*, *New Duolingo*, and *Google Assistant*. Of all the previously mentioned websites, they share the use of AI to make accommodating the user's needs a feasible task. Taking a closer look into the programs behind the math website, *Aleks* employs adaptive algorithms that assign tailored content to each student profile. The website has taken notice of mapping the details of the student's knowledge, specifically attentive to what topics the student grasps. *Aleks* also has taken notice of students' repetition of mistakes and can further guide a student through hints, suggestions, or providing different subjects to attempt. Similarly, *Quizlet* applies adaptive self-generating quizzes and flashcards that accommodate the student's patterned behaviors. In the case where a student repeatedly makes similar mistakes, the artificial intelligence will use spaced repetition in order to ensure the student properly learns the commonly mistaken material. Moreover, each of the mentioned platforms provides feedback, while fostering a self-directed learning environment that allows students



the room to identify, and properly adapt to former weaknesses. These websites provide scaffolded learning in the sense that less help will be given as the student progressively improves in the previously weak subject. The artificial intelligence employed by these platforms not only enhances educational outcomes but also cultivates crucial critical thinking skills. The adaptivity found within both websites is what has led to their rise in popularity among students and the teachers who assign work through these websites. This resource is specifically helpful for teachers as it removes inhibitions due to time restraints. Educators are simply able to assign students a task, in this case for *Aleks*, and the website will automatically cater to an individualized profile per each attending student. All aspects of creating assignments, implicating scaffolding, and monitoring induced frustration through progressive materials will be left up to the AIED to do without the need for extensive and deliberate monitoring from the teacher. With this in mind, teachers can reshift their focus to different aspects of the classroom and the material being taught, specifically in the manner it is being taught. Many teachers will become better educators as well as shift to a more positive effect, this change in demeanor will be noticed by students. Teachers who exhibit higher levels of positive affect will appear to convey more emotions such as enthusiasm, warmth, and admiration, all of which foster a supportive environment for students to engage within (Owusu-Fordjour, 2021). Emotional contagion often facilitates a more affluent classroom atmosphere in which students feel empowered to actively participate in classroom activities. Additionally, teachers with elevated affect are more likely to employ various instructional strategies, doing so will cater to the diverse needs of students seeking a deeper grasp and retention of the curriculum. Teachers who apply dynamic teaching are more likely to hold the attention of students, as well as enhance academic achievements, and cognitive development, and apply critical thinking to school assignments. Positive affect in teachers engenders deeper bonds between student-teacher relationships. In cases like this, nurturing relationships will add to the classroom again as students will be more inclined to participate, improve academic performance, and boost confidence in the environment. The vast manifold of variables that improve due to a positive effect from teachers is simply a contribution that should not be ignored within our education system. Overall, the plethora of influences on a student's academic accomplishments is vast and interconnected amongst many other aspects such as the teacher, curriculum, and peers within the classroom. Through the methods of implementing AIED throughout classrooms, ensuring the educational experience for both teachers and students alike will change the overall quality demonstrated of what the education system could provide. Optimally adapting education that caters to an individual student was a principle advocated and practiced by ancient Greek philosophers, specifically that of Plato. The principle of individualized education emerged as a fundamental principle during Greece as it highlighted a students' individual abilities, interests, and aptitudes were accustomed and cultivated to the fullest extent. Specifically, by doing such an individualized system, the universal one-size-fits-all model was being deconstructed. Plato's dream of education could revitalize a needed paradigm shift within modern education to create a more immersive experience in education. Though one-to-one teacher-to-student classrooms may not be possible for such a vast range, the power of AIED is to achieve a system that closely replicates such principles that serve as a transformative force in shaping individual students into virtuous and enlightened citizens. The promotion of intrinsic motivation through engaging courses will spark the love for learning within students once more. Moreover, an individualized approach allows for the identification and remediation of weak areas within a



student's knowledge, ensuring no student is left behind. By nurturing the unique talents and capabilities of each student, Plato's vision of education as a means of self-discovery and self-realization will add to a personalized learning system that establishes the best possible students out of everyday people.

Acknowledgements

- This summary was supported by my dear friend Rachael Requilemy who spent time into editing grammatical errors, discussing formatting, and giving feedback to the theories that went into writing this research paper. A large thank you also goes to my AP teacher Mrs. Lozada, and Lastly Dr. Yetkin for this phenomenal opportunity.
- This article was presented at the **12th London International Conference, held on 23-25 April 2024 in the Netherlands**. It has been published in the proceedings of the London International Conferences under No. 10 (2024).



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