A Synthesis Proposal: Merging AI in Education with Automata Theory

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Abstract

As classroom sizes expand, formal education faces increased challenges in providing scalable, targeted feedback based on student engagement. $CS250$, an undergraduate core course in discrete mathematics, covers topics such as logic, elementary number theory, proof by induction, recursion on trees, search algorithms, regular languages, finite state machines, and computability. These concepts often present challenges due to their abstract nature and the precision required in logical reasoning. Primarily enrolling computer science and related majors, the course benefits from reusable learning objects (RLOs) designed to support concept mastery. In this context, the author proposed a new discussion material on mathematical foundations, specifically targeting regular language expression. He tested a Python tool that allowed students to check their answers' correctness while mastering regular language expressions. Students completed the Python tool and a survey, which confirmed the tool's usefulness and provided valuable feedback for iterative design.

This paper aims to contribute to the existing body of knowledge on AI in education by shedding light on student perspectives with RLOs. In future iterations, we plan to recruit a more diverse range of educators, including female educators from all-women colleges, to broaden our perspective on instructional effectiveness. Moving forward, we seek to explore the balance between technological and human interventions required for effective course delivery. Although these findings are preliminary, continued research and richer data may reveal organic, inductive themes as this iterative process unfolds.

Keywords

AI in Education, Automata Theory, Synthesis Proposal, Doctoral Consortium, Regular Expressions, Reusable Learning Objects (RLOs)

1. Introduction

As classroom sizes expand, educators increasingly need scalable, targeted feedback mechanisms to support student engagement. $CS250$, an undergraduate core course in discrete mathematics at UMass Amherst, covers key topics such as logic, elementary number theory, proof by induction, recursion, search algorithms, regular languages, finite state machines, and aspects of computability [1]. These concepts challenge students due to their abstract nature and the logical precision they demand.

To address these challenges, the author developed a Reusable Learning Object (RLO), which refers to "any digital resource that can be reused to support learning" [2]. The RLO incorporates modular, adaptable resources that support specific educational goals. In this context, the RLO focuses on simplifying complex topics in $CS250$ through interactive and reusable digital content, helping students engage independently with difficult concepts, especially those involving regular expressions.

The RLO includes several key components: a Python-based interactive tool for answer verification, structured practice exercises, and integrated feedback mechanisms that guide students through the learning process. Designed to actively support students, the RLO delivers immediate feedback to help them correct errors and strengthen their understanding. During the study, the author assigned a treatment group to use the RLO for regular expression exercises, where students received instant feedback as they practiced. The study also included pre- and post-surveys with the treatment group, capturing changes in understanding and perceptions.

Survey responses indicated that the RLO was primarily used for reinforcing course material and problem-solving skills, with many participants planning to apply these skills directly to their $CS250$ assignments and exams. Participant #2 noted, "Yes, it was very useful in helping check work," while Participant #5 highlighted the tool's benefit in understanding regular expressions, stating, "I would recommend it to others because it was helpful in understanding how regex are set up." However, some participants felt the tool's feedback was not sufficiently personalized, as Participant #6 remarked, "It wasn't personalized, but it was useful," indicating that while beneficial, it did not offer individualized guidance.

A number of participants also suggested improvements to make the tool more user-friendly and accessible. For instance, Participant #3 recommended "more language options" and "text-to-speech" functionality, reflecting a

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desire for inclusive design to meet diverse learning needs. Initial usability challenges were also reported, with Participant #1 mentioning, “I wasn’t sure how to use the tool at first,” emphasizing the importance of an intuitive user experience. Participant #15 expressed reluctance to recommend the tool, commenting, “I would not recommend the tool to others; it did not explain very much and took a long time to run,” highlighting areas for improvement in efficiency and instructional depth. While the RLO was seen as helpful for coursework, some participants were uncertain about its long-term applicability, as Participant #12 noted, “I do not plan to use it in my personal life,” suggesting that its perceived value was largely limited to immediate academic goals.

Through an iterative design process, the author structured the RLO to enhance student engagement by allowing them to interact with content at their own pace. In this paper, the author uses the terms "Learning Object" and "Reusable Learning Object" interchangeably to describe these modular educational resources [3].

Beyond promoting independent learning, the RLO aims to increase engagement, strengthen problem-solving skills, and improve students’ ability to master abstract mathematical concepts. Prior research highlights how learning analytics and feedback within RLOs can enhance learning outcomes, especially in skill-based subjects like those in $CS250$ [4, 5]

The next sections address the related works, the study design, development, and testing to ensure the RLO’s reusability. Finally, the author outlined a plan for a proof of concept, drawing from the doctoral program insights, related works and testing within real-world educational contexts. Future endeavors, especially in the context of a doctoral program, require continuous refinement and optimization of the initial concept as presented herein to achieve the best outcomes.

2. Related Works

As classroom sizes expand, educators face increased challenges in providing scalable, targeted feedback based on student engagement [6]. The application of AI in education addresses these issues through tools like Intelligent Tutoring Systems (ITS), adaptive content creation, and automated administrative tasks [7, 8]. AI in education combines multiple fields—learning science, human-computer interaction (HCI), software engineering, natural language processing (NLP), and machine learning (ML) [9]. However, developing effective ITS tools requires seamless integration of advanced algorithms, deep pedagogical knowledge, and user-centered design [10].

Steve Blank’s Customer Discovery framework, as outlined in the NSF I-Corps Teaching Handbook, reinforces this interdisciplinary approach by emphasizing iterative development and user feedback, ensuring that adaptive tools like ITS are aligned with real-world educational needs and specific challenges faced by students, instructors, and administrators [11]. This process aligns with AI’s objectives in education by fostering adaptable and scalable solutions suitable for diverse learning contexts.

Implementing a SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis further aids in evaluating the feasibility of adaptive learning technologies, identifying strengths like personalized learning pathways and addressing limitations such as data privacy concerns [**?**]. Together, Steve Blank’s framework and SWOT analysis underscore the importance of developing adaptive educational tools that effectively respond to the evolving needs of educational stakeholders [8].

Moreover, adaptive algorithms similar to those employed in fields like gaming—where neural networks, enhanced by genetic algorithms, refine responses based on real-time performance feedback—illustrate how iterative adaptation could similarly benefit educational contexts [12]. Such an approach could allow educational AI systems to adjust dynamically to varying learner progressions, supporting engagement and promoting personalized learning paths across diverse skill levels.

3. Study Design

The study design happened as an iterative process. First the authored created a pilot project as a proof of concept. Thereafter, the author became the entrepreneurial lead for Team Intelligent Tutoring Systems R Us. Team Intelligent Tutoring Systems R Us obtained U. S. National Science Foundation’s Innovation Corps (I - Corps™) Customer Discovery Project funding.

3.1. Course Pilot Project

As part of teaching assistant preparation course, the author and classmates conducted a pilot study without Institution Review Board (IRB) approval. The pilot study ended with 147 participants in March-May 2022.

In pilot study, they introduced a python script and sought to probe students’ reactions to its usefulness as a RLO.

They designed the RLO to enhance the students’ understanding of a regular expressions. During the pilot study, they gave participants the Python script along with instructional materials for completing a series of tasks. The study concluded with a survey featuring open-ended questions to collect qualitative data on the students’ experiences and feedback.

The survey responses varied significantly. Over 31.3% of participants reported “no challenges,” indicating a smooth experience with the Python script. In contrast, under 15.6% of participants expressed difficulties, with comments such as "I found the instructions hard to follow and get the code running." These responses highlighted areas for instructional materials improvements.

Additionally, 24.7% of participants, particularly those majoring in computer science, showed motivation towards the concept of using programming in their coursework. These students appreciated the practical application of programming skills and expressed interest in further integrating such tools into their studies.

Overall, the pilot study provided valuable insights into the effectiveness of the RLO and the Python script. The feedback collected not only show improved student learning experience but also aided the instructional materials refinement as part of an IRB protocol (See Figure#1).

3.2. U.S. National Science Foundation's Innovation Corps (I-Corps™) Customer Discovery Project

The National Science Foundation (NSF) I-Corps Teams program provides an intensive seven-week entrepreneurship training course with mentorship and funding for customer discovery. As part of this program, the author led Team Intelligent Tutoring Systems R Us as the entrepreneurial lead, receiving a travel grant supported by Cornell Tech and the National GEM Consortium to explore market potential for the Reusable Learning Object (RLO) project [13].

The I-Corps program guided the team in conducting a hybrid field study to test initial hypotheses and make adaptive pivots. Insights from customer discovery interviews were essential in refining the RLO's interface and feedback mechanisms. This process identified key challenges, value propositions, and market opportunities, structured within a business model framework as illustrated in the SWOT analysis (See Figure 2). Future work includes developing a comprehensive Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis as preparation for a national I-Corps application and further expanding the study's scope.

3.2.1. I-Corps Research Questions and Hypotheses

1. What value propositions exist for students, professors, and administrators in using adaptive learning tools for instructional support?
2. STEM students seek adaptive tools to aid in content mastery and skill development, including grit, motivation, and soft skills beyond technical competence.
3. STEM instructors desire adaptive tools that simplify grading, enable course scalability, and introduce innovative learning experiences.
4. Administrators aim to boost institutional ranking through future-generation technologies while addressing academic integrity, accessibility, and privacy concerns.

3.2.2. I-Corps Study Methods

1. **Customer Segmentation:** The team focused on understanding the mental models of STEM students, professors, and administrators, exploring their behaviors, characteristics, and needs.
2. **Customer Discovery Interviews:** Using a hybrid approach of virtual and in-person interviews, the team engaged participants to uncover educational pain points and evaluate the RLO's commercial viability.
3. **Data Collection and Analysis:** With over 90 contacts from 15 colleges and universities, the team conducted 35 detailed interviews with students, instructors, and administrative professionals in instructional roles.

3.2.3. I-Corps Conclusion

The team initially accepted the null hypothesis but discovered a strategic pivot by broadening customer segmentation beyond the host institution. This pivot enabled the development of a more dynamic business model, continuously revised through customer insights. Aligning with Woolf et al.'s *AI Grand Challenges*, future goals include creating intelligent tutoring systems, real-world simulation environments, and natural language processing capabilities to enhance adaptive learning [8, 7].

4. Study Development

This study employed a mixed-methods research design, consisting of both quantitative and qualitative data collection and analysis. The author conducted three phases:

- Phase 1: Literature Review and Case Studies. The first phase of the study involved another comprehensive review of the literature on the use of AI in Education. This phase helped to identify best practices and potential challenges associated with using AI in Education. During this phase, the author worked with an undergraduate student to complete an Honors Thesis Project, where the author served as a committee member.
- Phase 2: Surveys and Interviews. The second phase of the study involved the administration of surveys and interviews to educators, teaching assistants, and students. The surveys and interviews assess perceptions of RLOs and its potential impact and other considerations.

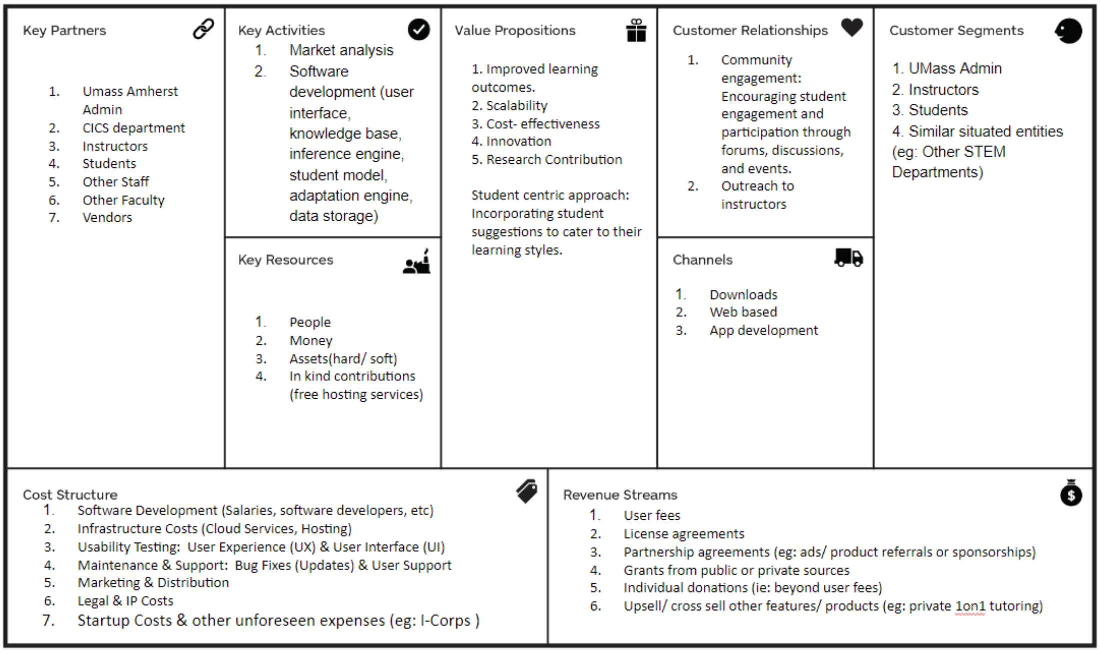

Figure 1: Team Intelligent Tutoring Systems R Us utilized Steve Blank's Customer Discovery framework and Alexander Osterwalder's Business Model Generation along with methods used by the National Science Foundation (NSF).

- Phase 3: Analysis and Synthesis. The third phase of the study involved the analysis and synthesis of the data collected in phases 1 and 2. Quantitative data analyzed using descriptive and inferential statistics, while qualitative data analyzed using content analysis. The results of the analysis synthesized to identify best practices and potential recommendations for future research and practice.

After beginning Phase 1, the author collaborated with an undergraduate student on the Honors Thesis Project committee to explore educators' mental models and perspectives on how RLOs impact learning. Key research questions included:

1. How does the RLO compare with traditional methods in understanding regular expressions?
2. How does the RLO shape students' problem-solving skills?
3. Does RLO use deepen understanding of automata principles?
4. What is the connection between RLO engagement and CS250 performance?
5. How do demographics correlate with learning outcomes?

4.1. IRB Protocol

The entire process adhered to ethical guidelines outlined in the IRB protocols #5139 "Team Chase Undergraduate Research Volunteers (URV)" and #5358 "AI in Education and Automata Theory: Synthesis Proposal".

4.2. Study Testing

4.2.1. Consent Form

Before conducting interviews with educators, participants were required to provide informed consent. The consent form outlined the purpose of the semi-structured interview, which aimed to contribute to an honors thesis exploring adaptive learning tools for future-generation technologies within the realm of AI in educational Reusable Learning Objects (RLOs). The research study was designed to unpack the mental models surrounding AI in education. Eligible participants for the study included instructors and teaching assistants specializing in areas such as proofs, induction, reason, number theory, automata theory, regular expressions, finite state machines, and related courses. We informed participants that the interview lasted approximately 20 minutes and primarily focused on soliciting their opinions and views regarding their experience with curriculum development and AI in Education, as well as related research topics.

Figure 2: SWOT analysis pulled from the SWOT Analysis on AI in Education by Andre Kenneth Chase Randall [14]

The interview posed minimal risks such as potential fatigue or boredom. We disclosed risks and encouraged to adhere to the 20-20-20 rule for eyestrain and to maintain hydration throughout the interview. The 20-20-20 rule advises taking a 20-second break from looking at screens every 20 minutes. During this break, focus on something at least 20 feet away. This practice helps prevent eye strain and fatigue caused by prolonged screen use. The consent form also covered data privacy, assuring participants that personal information would be handled confidentially with the IRB protocols. Data collection will be conducted anonymously with transcribed interviews in the study's codebook. Communication on any concerns was encouraged throughout the interview as well. The consent form process and interview protocol were carefully designed to uphold ethical standards, ensure participant confidentiality and comfort, and facilitate valuable insights into participants' mental models surrounding AI in education.

Table 1

Description of our participants for semi structures interviews. Eligible participants for the study included instructors and teaching assistants with selfdescribed expertise within the discrete mathematics area such as proofs, induction, reason, number theory, automata theory, regular expressions, finite state machines, and related courses.

Institution	TA	Instructors
University of Massachusetts Amherst	3	1
University of Pennsylvania	0	1
University of California Berkeley	0	2
Cornell University	0	1
Total	**3**	**5**

4.2.2. SEMI-STRUCTURED INTERVIEW SCRIPT

We designed the questions to explore educators' mental models regarding their teaching experiences and perspectives on adaptive learning tools. Some questions were adapted from the I-Corps customer discovery project to ensure depth in understanding both practical and attitudinal dimensions of their insights. The specific questions

Table 2
Usability Testing Participants; 44 participants completed the consent forms, pre survey, and post survey. 65 students opted to use the alternative research for the option to get two extra credit points with 194 students opting not to partici

Group	Number of Students
Treatment Group	44
Control Group	65
Non-participants	194
Total	**303**

included are as follows:

1. **Course Background**: Educators describe their teaching context.
2. **Teaching Challenges**: Identification of course-specific challenges.
3. **Adaptive Solutions**: Educators suggest solutions to their teaching challenges.
4. **Solution Drawbacks**: Exploration of limitations in current methods.
5. **Design Preference**: Educators explain why preferred designs are effective.
6. **Teaching Assistant Roles**: Understanding TA responsibilities in supporting adaptive tools.
7. **Adaptive Tools Perspective**: Insights on potential and challenges of adaptive tools.
8. **Incorporation Process**: Discuss practical steps for tool implementation.
9. **Tool Features and Functionality**: Discuss expectations for tool features to aligned with teaching styles.
10. **Professional Recommendations**: Suggestions for other participants in adaptive learning studies.
11. **Additional Insights**: Educators provide thoughts on adaptive learning tools.
12. **Open Feedback**: Educators can add any other relevant thoughts.

From interview with instructors and teaching assistants, we gain insight into teaching experiences, adaptive learning perspectives, and practical integration strategies. Generally, interviewees highlighted several common themes:

Challenge in Differentiating Instruction: Educators often noted difficulty in addressing the varying levels within a single classroom and expressed interest in tools to support personalized pacing.

Positive Reception for Adaptive Tools: Many valued adaptive tools for their potential in enhancing concept retention and student engagement, specifically when tailored to individual learning trajectories.

Implementation Considerations: Practical constraints, including time, ease of integration with current learning management systems, and reliance on teaching assistants, were often mentioned as significant factors influencing tool adoption.

This feedback forms a basis for refining adaptive learning tools to meet real-world teaching demands.

5. Conclusion and Future Work

One of the most notable advantages of AI in education is its ability to personalize learning, tailoring educational experiences to meet the diverse needs, preferences, and learning styles of students [15]. Using an RLO as the foundation for intelligent tutoring systems could enhance the educational landscape by providing customized learning paths and tailored feedback [9]. Participant feedback in this study highlighted the RLO's potential for supporting course material and fostering problem-solving skills, with Participant #2 noting, "Yes, it was very useful in helping check work." Participant #5 also recommended the tool, sharing that "it was helpful in understanding how regex are set up."

Despite these benefits, participants expressed a desire for more personalized feedback. As Participant #6 remarked, "It wasn't personalized, but it was useful," underscoring the need for individualized support within such tools. Suggestions for improvement, including "more language options" and "text-to-speech" functionality (Participant #3), point to the importance of accessibility and adaptability in future RLO iterations. Additionally, feedback from Participant #1, who stated, "I wasn't sure how to use the tool at first," indicates that enhancing user guidance could improve ease of use. Comments from Participant #15, who noted, "I would not recommend the tool to others; it did not explain very much and took a long time to run," suggest areas for improving efficiency and instructional depth.

Future work on this RLO aligns with the *AI Grand Challenges for Education* outlined by Woolf et al., particularly the goals of providing "mentors for every learner" and "lifelong and life-wide learning" [8]. In line with AI's strengths, weaknesses, opportunities, and threats in education, as explored by Randall in recent discussions with HBCU faculty [**?**], future RLO development will focus on designing adaptable tools to support students from varied backgrounds, ensuring inclusivity, accessibility, and effectiveness. Planned enhancements include:

- **Adaptive Assessment and Skill Tracking**: Implementing a system that tracks student performance to provide tailored difficulty levels and additional exercises based on individual progress.
- **Dynamic Hints and Explanations**: Adding context-aware hints that address specific errors, such as syntax misunderstandings in regular expressions, and provide tailored guidance.

- **Immediate Corrective Feedback**: Offering formative feedback that is specific to the type of error made, enabling students to correct misunderstandings promptly.
- **Personalized Learning Pathways**: Creating customized learning pathways based on initial assessments or adaptive quizzes, allowing students to focus on areas that require reinforcement.
- **Progress and Performance Dashboards**: Developing dashboards that give students personalized insights into their strengths and areas needing improvement, supporting self-directed learning.
- **Natural Language Processing (NLP) for Open-Ended Responses**: Using NLP to analyze open-ended responses and provide customized feedback based on the semantics of students' answers.
- **Gamification and Motivational Feedback**: Incorporating gamified elements that reward individual achievements and keep students motivated throughout their learning journey.
- **Student Profile Customization**: Enabling students to set preferences or learning goals within the RLO, allowing it to customize feedback based on their unique needs and learning styles.

These enhancements aim to make the RLO a more flexible, accessible, and impactful educational tool that supports a broad range of learners. By focusing on personalization and adapting to diverse learning needs, this RLO aligns with AI's grand challenge to democratize educational resources and extend individualized learning opportunities beyond traditional settings.

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7. Appendices

7.1. Appendix A: Automata Theory Discussion Objectives

Every week for the length of the course, students met for a 50 minutes discussion group to cover the following topics:

1. **"What is a Proof?"**
    - Objective: To foster an understanding of mathematical proof in real-world scenarios and to practice constructing proofs based on definitions, highlighting the role of preconditions, postconditions, and loop invariants in validating code.
2. **"A Murder Mystery"**
    - Objective: To develop deductive reasoning skills using propositional logic, demonstrating the process of narrowing down possibilities based on given clues, and applying rules of propositional logic to deduce conclusions efficiently.
3. **"Practicing Proofs"**
    - Objective: To enhance proficiency in applying proof methods to statements about functions and relations, emphasizing predicate proof rules and the significance of properties of functions and relations.
4. **"Infinitely Many Primes"**
    - Objective: To apply proof techniques and congruence principles to establish and understand facts about prime numbers, specifically the infinitude of primes.
5. **"Practicing Induction Proofs"**
    - Objective: To cultivate a strong foundation in mathematical induction, focusing on the structure of induction proofs including base cases, inductive hypotheses, and inductive steps.

6. **“More Induction Problems”**
   - Objective: To reinforce and expand students’ skills in mathematical induction, challenging them with diverse problems that require careful proof construction.
7. **“Boolean Expressions”**
   - Objective: To familiarize students with Java-based boolean expressions, emphasizing the differences between common programming languages and the structure of tree representations in code.
8. **“Course Evaluation Essay Questions”**
   - Objective: To gather feedback on the course content, pedagogy, and overall learning experience, aiding in future improvements and refinements.
9. **“Designing Regular Expressions”**
   - Objective: To master the art of constructing accurate regular expressions for specified languages, promoting a systematic approach to capture all desired strings while excluding undesired ones.
10. **“Minimizing a DFA”**
    - Objective: To comprehend the principles behind the Myhill-Nerode Theorem, and to acquire hands-on experience in minimizing DFAs by leveraging the equivalence classes of the relation on strings.
11. **“Applications in Compilers”**
    - Objective: To understand the foundational role of deterministic finite automata in the lexical analysis phase of compilers, underscoring the transition from high-level programming languages to machine-understandable code.

7.2. Appendix B: Discussion #8 on Regular Expressions

Writing Exercise:

Construct a regular expression for the set EE ("even-even") of strings in $\{a, b\}$ that have both an even number of $a's$ and an even number of $b's$. Justify your answer carefully – explain why your expression generates only even-even strings and why it generates all even-even strings.

Note that all even-even strings have even length, so you may think of the whole string as being broken up into two-letter blocks.

Here are some more hints. You are not required to use them to solve the main problem, but they will probably be useful.

Define the language EEP (“even-even-primitive”) of nonempty strings that are in EE and have no proper prefix in EE. (That is, if $w \in EEP$ and $w = uv$ with both u and $v \in EE$, then either u = or v = .) It turns out that while EEP is harder than EE to describe in English, it has a simpler regular expression.

• Explain why $EE = (EEP)$

• Which strings of up to six letters are in EEP?

• Construct a regular expression for EEP, and explain why this solves the main problem.

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