Using Artificial Intelligence to Teach and Learn the Formal Languages and Automata Course at the University of Nariño

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Abstract
Representing knowledge can be a challenging task in undergraduate education. In the Formal Languages and Automata course, developing the ability to depict knowledge is crucial, and graphical methods are highly beneficial. Pre-conceptual schemas are graphs using controlled language, and they are simple to use and represent knowledge in any context. Despite their widespread use in academic circles, no computational tools currently incorporate artificial intelligence into such Pre-conceptual schemas, making it hard for computers to understand them. This study investigates a new method for computer interpretation of knowledge using artificial intelligence, aiming to enhance teaching, and learning in the Formal Languages and Automata course at the University of Nariño in Colombia. The outcomes of the validation process indicate a positive impact on educational practices, laying the groundwork for future innovations in the fields of didactics and computer-aided educational tools.

Keywords: Knowledge, Representation, Pre-conceptual Schema, Artificial Intelligence, Formal, Languages, Automata

Introduction

Knowledge representation in undergraduate education presents a notable challenge, particularly in technically demanding courses such as Formal Languages and Automata, where clarity and precision in presenting information are paramount. In such contexts, using graphical techniques emerges as a highly effective strategy. By their very nature, these visual tools provide a lucid and engaging way to demonstrate complex concepts, making them more accessible to students. Through graphs, abstract theories and principles are transformed into tangible visuals, facilitating a deeper understanding and retention of the subject matter. Despite the simplicity of graphs, their eminently mathematical and algebraic nature makes the knowledge representation a task that demands a significant effort in abstraction.

Pre-conceptual schemas stand out for their simplicity and effectiveness in encapsulating complex knowledge using straightforward graphs and a controlled vocabulary. These schemas excel in adapting to many scenarios, making them a favoured tool in educational environments for their ability to distil and communicate intricate ideas. However, a notable gap exists in integrating these schemas with computational technologies, particularly in artificial intelligence (AI). This lack of AI-enhanced tools to work alongside Pre-conceptual Schemas limits the capacity of computers to interpret and interact with the knowledge these schemas represent. Overcoming this hurdle is essential for advancing pre-conceptual schemas in digital and AI-driven educational platforms, which have immense potential for enhanced learning and knowledge processing.

This study delves into a pioneering methodology aimed at empowering computers to decipher and assimilate knowledge via artificial intelligence, focusing on refining the educational journey within the Formal Languages and Automata course at the University of Nariño in Colombia. By harnessing the capabilities of artificial intelligence, the research seeks to bridge the gap between complex academic concepts and their digital comprehension, facilitating a more interactive and practical learning environment. This innovative approach promises to enhance students' grasp of intricate subjects and to pioneer new frontiers in the application of AI in educational settings, potentially transforming traditional pedagogical techniques and setting a novel approach to academic experiences.

The initial findings from the validation stage of this research indicate a promising potential for this novel method to improve educational approaches. These early successes lay a solid groundwork for future enhancements in teaching methodologies and the creation of new computer-assisted learning tools. This approach paves the way for innovative educational practices by demonstrating significant benefits in conveying and understanding knowledge. It opens avenues for further research and development in digital learning resources, potentially revolutionising the traditional classroom experience and setting new benchmarks for integrating technology into education.

This article is organised into six sections. The second section includes a literature review. The third section depicts the problem statement and methodological aspects. The fourth section describes the proposed solution. The fifth section contains the validation process and its results. Finally, the last section includes the discussion, conclusions, and future work.

Literature Review

Teaching formal languages and automata has seen significant advancements over the years. This chapter explores various research contributions that focus on enhancing this area's teaching methodologies, tools, and theoretical underpinnings. The literature reviewed includes dissertations, journal articles, conference papers, and educational tools, providing a comprehensive overview of current research and practice in teaching formal languages and automata.

Aruleba (2020) explores a novel approach to teaching automata by extracting finite automata from hand-drawn images. This dissertation highlights the potential of integrating image processing techniques with automata theory to create an engaging learning experience. The study demonstrates how hand-drawn sketches can be converted into digital representations of finite automata, providing an intuitive way for students to understand complex concepts. This method bridges the gap between abstract theory and practical visualisation, making automata theory more accessible to learners.

Askarpour (2021) discusses the challenges and observations related to the transition to online teaching in computer science, which includes the teaching of formal languages and automata. The paper, published on arXiv, provides insights into the adaptations required for effective online education. It emphasises the importance of interactive and adaptive learning environments, which can support the unique needs of students learning complex theoretical concepts remotely. The shift to online education has necessitated the development of new teaching tools and methodologies, which are critical for maintaining the quality of education in this field.

Cleaveland (2022) contributes to the theoretical enhancement of automata by integrating process algebra. This work, part of a collection of essays dedicated to Frits Vaandrager, demonstrates how process algebra can be used to improve the design and analysis of automata. By leveraging the formalism and rigour of process algebra, educators can provide students with a deeper understanding of automata's operational behaviours. This integration also offers new perspectives and techniques for teaching complex automata concepts, enriching the educational curriculum.

Goyal and Sachdeva (2009) propose a method to enhance the teaching of the theory of computation by integrating it with other courses. Published in the International Journal of Recent Trends in Engineering, their work suggests that a multidisciplinary approach can make theoretical concepts more relevant and understandable. Students can see the broader context and significance of their learning by connecting automata theory with practical applications in other computer science courses. This approach reinforces theoretical knowledge and fosters a holistic understanding of computer science.

Jordaan, Timm, and Marshall (2023) present AutomaTutor, an educational mobile app designed to teach automata theory. Presented at the Brazilian Symposium on Formal Methods, this app uses interactive exercises and real-time feedback to enhance student engagement and learning outcomes. The mobile app format allows for flexible, self-paced learning, which is particularly beneficial in the current educational landscape, where digital tools are increasingly important. AutomaTutor exemplifies the use of technology to make learning more accessible and practical.

Ramos (2022) evaluates the usability of the OFLAT platform, a tool designed to support the teaching and learning of formal languages and automata. This study focuses on how usability impacts students' learning experiences and outcomes. The findings suggest that user-friendly interfaces and intuitive design are crucial for successfully adopting educational tools. The usability evaluation provides valuable feedback for developers and educators aiming to create effective learning platforms.

Tecson and Rodrigo (2021) explore the impact of a self-paced tutoring system, ILSA, on learners' goal orientations. Their research at the International Conference on Information and Education Technology highlights the alignment between system utilisation and students' learning goals. The self-paced nature of ILSA allows students to engage with automata theory at their own pace, accommodating different learning styles and paces. This approach supports personalised learning experiences essential for mastering complex theoretical content.

Vayadande *et al.* (2022) investigate the simulation and testing of deterministic finite automata (DFA). Their work, published in the International Journal of Computer Sciences and Engineering, provides practical insights into applying DFAs in computational simulations. This research underscores the importance of hands-on experiences and practical applications in teaching theoretical concepts. By engaging in simulation and testing, students can better grasp the operational aspects of DFAs, enhancing their overall understanding of automata theory.

The reviewed literature demonstrates diverse approaches and tools to improve the teaching of formal languages and automata. These studies collectively contribute to a richer, more effective educational experience, from innovative technological solutions to theoretical enhancements and practical integrations. As the field evolves, ongoing research and development will be crucial in addressing the challenges and opportunities in teaching formal languages and automata.

Problem Statement and Research Methodology

Despite numerous tools designed to promote the teaching of formal languages and automata courses, the integration of AI in this domain remains in its initial stages. Many educational tools focus on traditional methods and digital aids, such as mobile apps and online platforms. However, the potential for AI to revolutionise this field is significant. AI can offer personalised learning experiences, automate assessment, and provide real-time feedback, enhancing learning. Nonetheless, the adoption of AI in teaching formal languages and automata is still emerging, indicating a need for further research and development to leverage its capabilities thoroughly.

One application of artificial intelligence is using alternative methods for representing knowledge through a controlled language. Pre-conceptual Schemas prove invaluable in this context as they offer a versatile way to depict knowledge, regardless of the specific domain or applied context. Given this situation, previous computational tools have yet to be capable of interpreting Pre-conceptual Schemas. This characteristic is the motivating factor for the development of this research, the direct application of which is developed during a Formal Languages and Automata course.

Knowledge representation can be performed using Pre-conceptual Schemas, as illustrated in Figure 1.

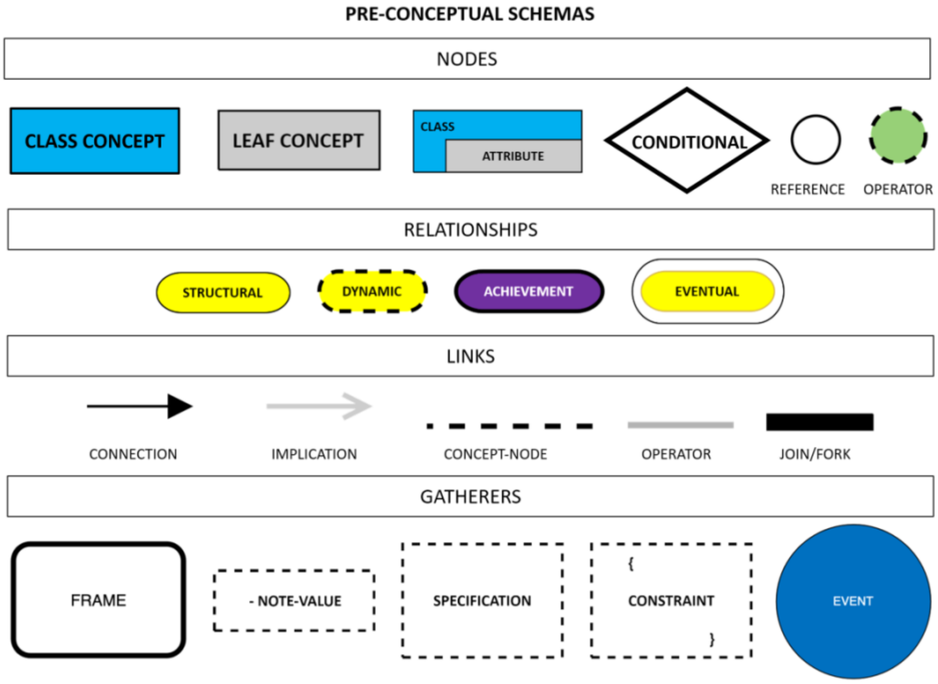

Figure 1: Pre-conceptual Schemas' Notation (Noreña, 2020)

Pre-conceptual Schemas serve to represent knowledge with well-defined semantics graphically. As Zapata (2007) noted, a Pre-conceptual Schema provides a way to specify structured ideas using a controlled language. Additionally, these schemas feature simple notation, are easy to comprehend, and can be adapted to any knowledge domain (Zapata, 2007). Thus, knowledge representations can be effectively conveyed through Pre-conceptual Schemas. Figure 2 depicts an example of how a Pre-conceptual Schema represents knowledge.

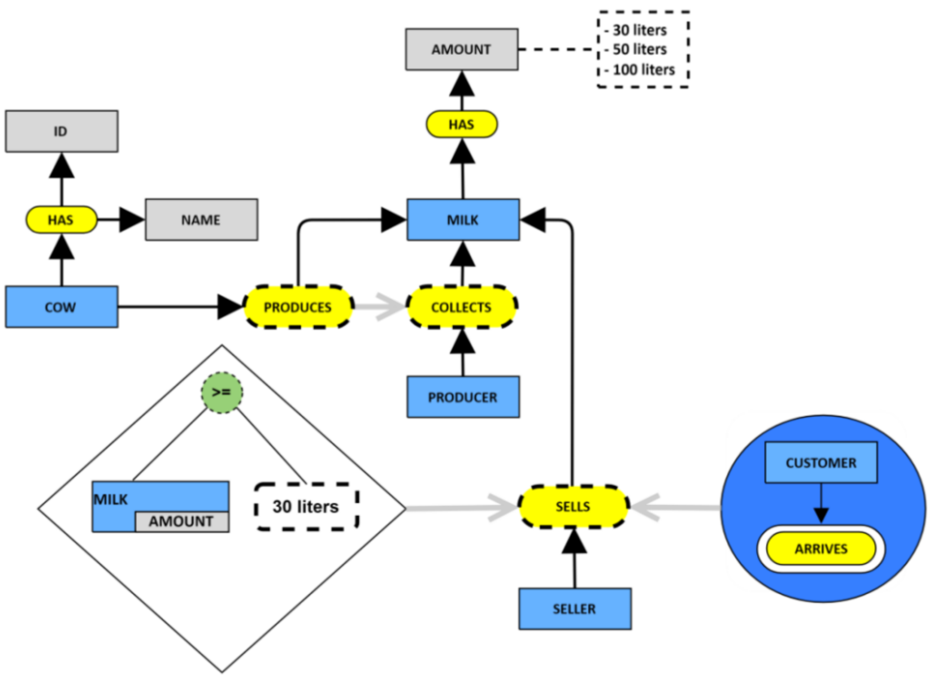

Figure 2: An Example of Representing Knowledge With a Pre-conceptual Schema

Our research is grounded in a qualitative paradigm, supplemented by elements of the quantitative paradigm, with an emphasis on the depth and richness of the collected data. This approach allows us to examine complex phenomena within their natural environments, providing the flexibility to understand and interpret the nuances of human behaviour and experiences. The qualitative method aligns well with our research objectives, enabling us to explore the subjective interpretations and meanings participants assign to their experiences, thereby offering a thorough understanding of the research topic (Fugard & Potts, 2015).

For this study, we employed a quasi-experimental approach, which involves deliberately manipulating or introducing a variable into a natural setting to observe the effects. This method allows for a combination of qualitative and quantitative research, enhancing the validity of the results like triangulation but leveraging the strengths of both approaches simultaneously (Daly *et al.*, 1992). Unlike traditional experimental methods, the quasi-experimental approach does not necessitate random assignment to control and experimental groups. This approach is particularly suitable for our study, as it permits a practical examination of phenomena where complete control over variables is impossible, thus balancing experimental rigour with real-world relevance (Asgari & Baptista, 2011).

The educational experience was developed with fifteen undergraduate students in systems engineering, who attended the course on formal languages and automata at the University of Nariño in Tumaco. We created the computational tool, and its application in such an educational experience was the basis of this study. We use eXtreme Programming (XP) as an agile methodology for designing and creating the computational tool. This way, we create a web-based computational solution called PCS-AI v1.0 (Pre-conceptual Schemas with Artificial Intelligence). The web-based tool is available online, and it is deployed at https://pcsaitech.com/.

Figure 3 depicts a photograph and some screenshots of students using PCS-AI v1.0. This computational tool allows users to create Pre-conceptual Schemas using predefined symbology.

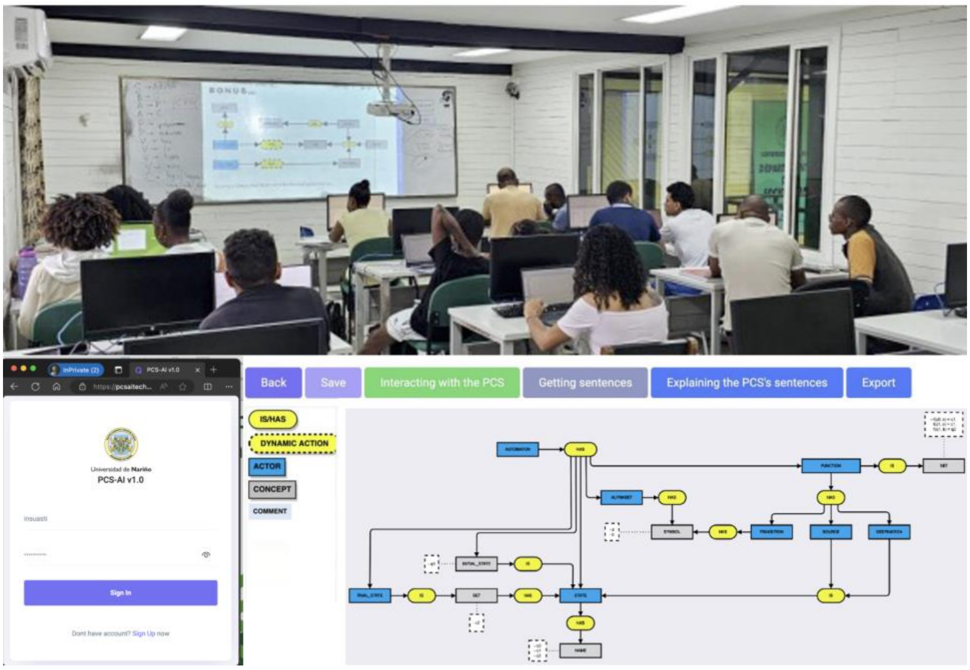

Figure 3: Educational Experience With PCS-AI v1.0

With the computational solution, students represent the knowledge associated with the formulation of a deterministic finite automaton (DFA), according to automata theory. A DFA is a theoretical model of computation used to recognise patterns within input data. A DFA consists of a finite set of states, a finite set of input symbols, a transition function that maps each state-symbol pair to a single state, an initial state, and a set of accepting states. The automaton processes an input string one symbol at a time, transitioning between states according to the transition function. It accepts the string if it reaches an accepting state at the end of the input (Hopcroft *et al.*, 2006). DFAs are crucial in the design of lexical analysers and other applications where precise and unambiguous pattern recognition is required (Sipser, 2013). They provide a clear framework for understanding the behaviour of simple computational devices and are foundational in the study of formal languages and automata theory (Lewis & Papadimitriou, 1998).

Findings and Discussion

The fifteen students' experience using the computational tool PCS-AI v1.0 within the Formal Languages and Automata course proved insightful and enriching. The students adeptly managed the computational tool, engaging with its advanced artificial intelligence features with remarkable ease. The intuitive interface of PCS-AI v1.0 allowed the students to quickly familiarise themselves with its functionalities, particularly the natural language processing (NLP) interface and the generative characteristics of the associated linguistic model.

Throughout the course, students used the NLP interface to generate Pre-conceptual Schemas, which served as the foundation for understanding complex topics within formal languages and automata theory. This interaction prompted the students to critically analyse and question the Pre-conceptual Schemas they generated. The tool's ability to provide comprehensive and coherent outputs based on the students' inputs allowed for a dynamic learning process where students could iteratively refine their understanding and approach to the subject matter.

The generative characteristics of PCS-AI v1.0's linguistic model further enhanced the learning experience. Students found that the tool could generate relevant examples and counterexamples, offering a robust mechanism for testing and validating their conceptual models. This feature was particularly beneficial in exploring the intricate nuances of formal language constructs and automata behaviour, as students could experiment with different inputs and observe the outcomes in real-time.

To gauge the effectiveness and impact of PCS-AI v1.0, a survey was administered at the end of the educational experience. The survey results were overwhelmingly positive, indicating that students found the tool user-friendly and educationally valuable. Most students reported that the AI-driven interactions significantly enhanced their comprehension of the course material. They appreciated the immediate feedback and the ability to explore formal language concepts hands-on and interactively.

Integrating PCS-AI v1.0 into the Formal Languages and Automata course facilitated a more engaging and effective learning environment. The student's ability to interact with the AI features of the tool not only supported their learning but also encouraged a deeper level of critical thinking and analysis. The favourable outcomes observed in the survey underscore the potential of AI-powered tools to enhance educational experiences, particularly in complex and abstract subjects like formal languages and automata theory.

According to the survey results, this real-time interaction has allowed students to understand more clearly the concepts associated with the representation of DFA. Figure 4 shows some screenshots of the activities conducted by the students in terms of interaction with the computational solution's artificial intelligence features.

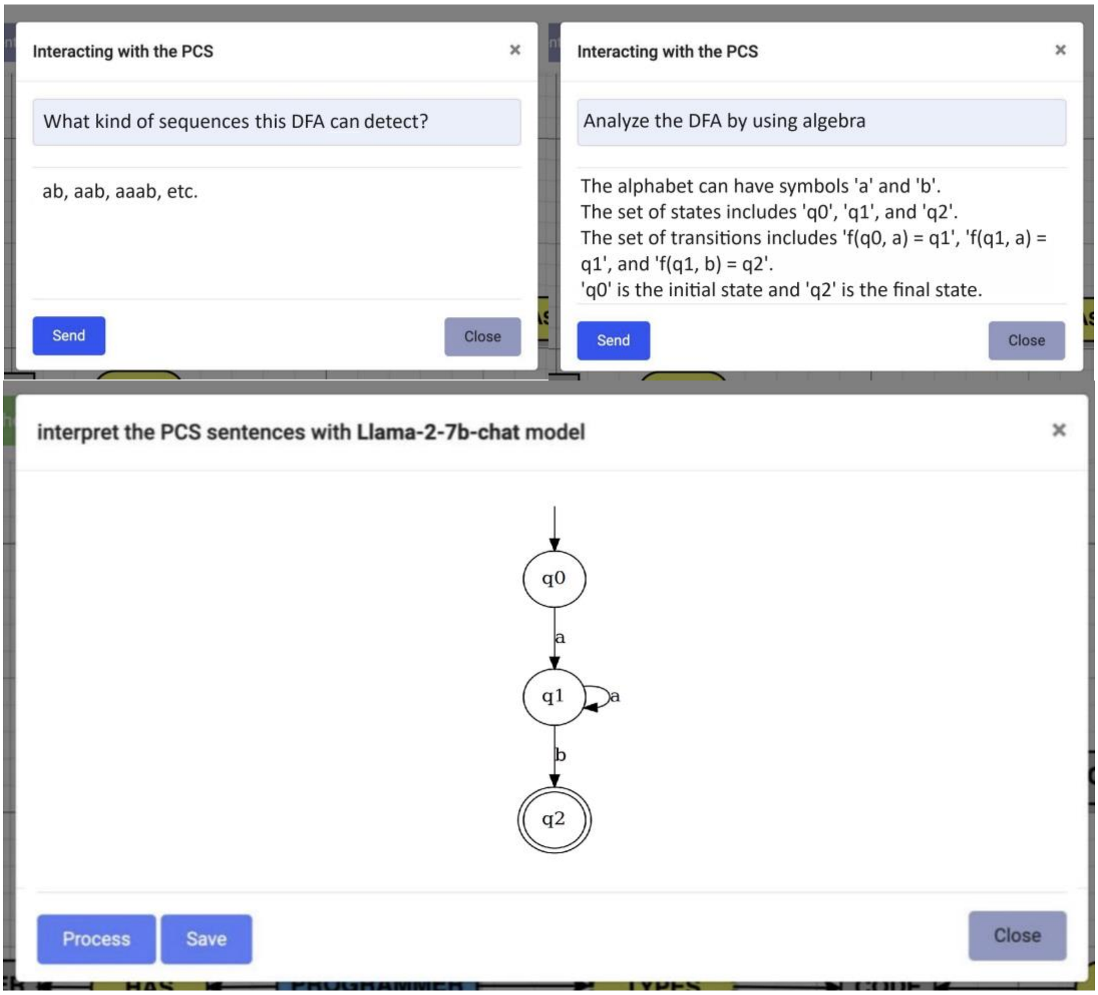

Figure 4: Some Interactions With the Pre-conceptual Schema and the Automatically Generated DFA

The functionality rating of the PCS-AI v1.0 tool, as presented in the bar chart of Figure 5, exhibits a consistently high performance among the fifteen students surveyed. Most ratings are clustered around 4 and 5, with the majority achieving a perfect score of 5. This suggests that the students found the tool highly functional for their educational purposes. The statistical summary supports this observation, with a mean of 4.87, a median of 5.0, and a mode of five. These measures indicate a robust central tendency towards the highest rating, signifying that the tool's functionality met or exceeded expectations for all participants.

The quality of the generated responses by PCS-AI v1.0 also received positive feedback, as evidenced by the bar chart. Like the functionality rating, most students rated the quality of responses as five, with a few giving it a four. The statistical summary reports a mean of 4.8, a median of 5.0, and a mode of five, reflecting a consensus on the high quality of the responses produced by the tool. This high satisfaction level underscores the tool's effectiveness in generating relevant and accurate responses for educational purposes in the Formal Languages & Automata course.

Another crucial metric evaluated is the likelihood of recommending PCS-AI v1.0 to others. The bar chart indicates that most students rated this aspect highly, with ratings of 4 and 5. The statistical summary reveals a mean of 4.73, a median of 5.0, and a mode of five. These statistics suggest that most students were likely to recommend the tool, highlighting their overall satisfaction and perceived value in their educational experience.

From a quantitative perspective, the survey results indicate that PCS-AI v1.0 performed exceptionally well in all three evaluated categories. The high ratings in functionality, quality of generated responses, and the likelihood to recommend the tool reflect the tool's significant impact and effectiveness in an educational setting, particularly for the Formal Languages & Automata course. The consistency of high scores across all three metrics suggests a well-rounded and reliable tool that meets the educational needs of students, supporting its continued use and recommendation in similar educational scenarios.

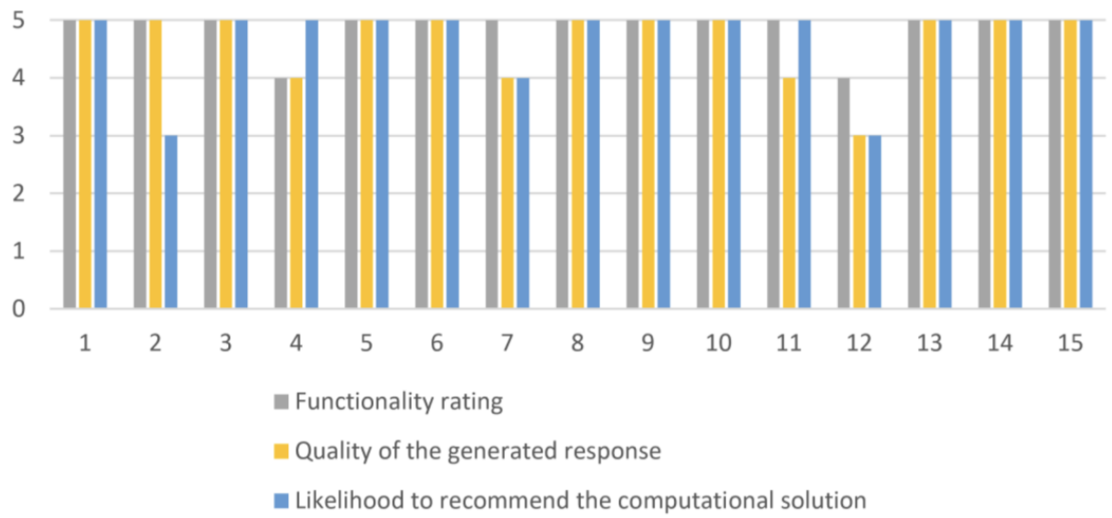

Figure 5: Quantitative Results of the Experience

The provided 3D bar chart in Figure 6 visualises the sentiment analysis of open-ended questions from the survey regarding the usage of PCS-AI v1.0 in the Formal Languages and Automata course. This qualitative analysis is categorised based on the sentiment polarity: very negative, moderately negative, moderately positive, and very positive.

The responses regarding the contextual problems students would like to address in the classroom reveal a mixed range of sentiments. Most responses fall into the positive and moderately positive categories, indicating that students feel optimistic about addressing these problems. However, there are also notable instances of moderately negative sentiments, suggesting that some students have concerns or reservations about the challenges they face in the classroom context. The very negative responses are minimal, indicating that while there are some significant issues, they are not widespread.

Students' opinions on using PCS-AI in the Formal Languages and Automata course are overwhelmingly positive. Most of the sentiment is concentrated in the moderately positive and very positive categories, demonstrating that students appreciate integrating AI tools into their learning process. This positive sentiment underscores the perceived benefits of PCS-AI, such as enhanced learning experiences and improved understanding of complex concepts. A few moderately negative sentiments suggest that while most students are satisfied, a few might have encountered issues or believe there is room for improvement.

Students expressed positive sentiments when asked about their confidence in teaching Formal Languages and Automata to another classmate using PCS-AI. The responses are heavily skewed towards the moderately positive and very positive categories, indicating that students feel confident using the AI tool effectively in a peer-teaching scenario. This confidence stems from their positive experiences and perceived tool mastery. However, a few moderately negative sentiments were also recorded, which may reflect individual variations in confidence levels or differing experiences with the tool.

The sentiment analysis of the qualitative responses indicates a positive reception of PCS-AI v1.0 among students in the Formal Languages and Automata course. Most sentiments are positive across all three queried aspects: contextual problems, opinions on PCS-AI, and confidence in teaching with PCS-AI. This positivity highlights the tool's effectiveness and the students' overall satisfaction. However, the presence of some moderately negative sentiments suggests that while the tool is well-received, there are areas where improvements could be made to enhance the user experience further and address any underlying concerns.

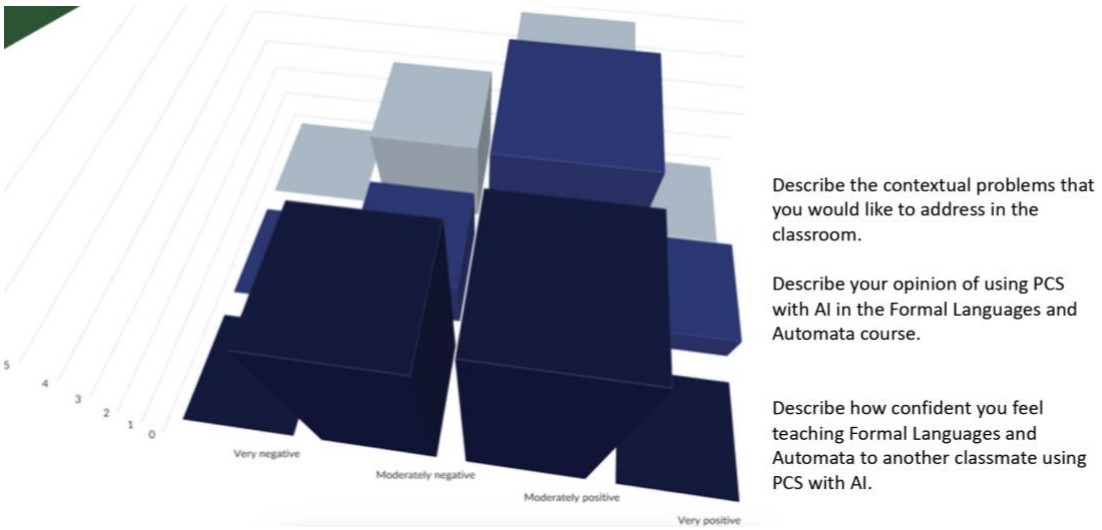

Figure 6: Qualitative Results of the Experience

The evaluation of PCS-AI v1.0 in the Formal Languages and Automata course encompasses quantitative and qualitative perspectives, offering a comprehensive understanding of its impact on student learning and satisfaction.

The quantitative analysis reveals high satisfaction levels among students regarding the tool's functionality, quality of generated responses, and likelihood of recommending PCS-AI. The functionality rating achieved an impressive mean of 4.87, with most students rating it a perfect five. Similarly, the quality of the generated responses and the likelihood of recommending the tool garnered high ratings, with means of 4.8 and 4.73, respectively. These metrics underscore the tool's robustness and efficacy in meeting educational needs. The consistently high ratings across these categories indicate that PCS-AI v1.0 is well-received and highly effective in enhancing students' learning experiences in the Formal Languages and Automata course.

Complementing the quantitative data, the qualitative analysis provides deeper insights into students' perceptions and experiences. Sentiment analysis of open-ended responses highlights a positive outlook towards PCS-AI. Students exhibited mostly positive sentiments when describing the contextual problems they wished to address, suggesting an optimistic view on tackling these challenges with the tool. Opinions on using PCS-AI in the course were overwhelmingly positive, reflecting the tool's perceived benefits in improving understanding and engagement with the course material. Confidence levels in teaching peers using PCS-AI were also high, indicating that students feel well-equipped to leverage the tool in a collaborative learning environment.

Integrating the quantitative and qualitative findings provides a holistic view of PCS-AI's impact. The high functionality rating and quality of generated responses align with the positive sentiments expressed in the qualitative analysis, reinforcing the tool's effectiveness. The likelihood of recommending PCS-AI, supported by qualitative feedback, underscores a strong endorsement from students, suggesting they find significant value in its use.

Despite the positive feedback, the qualitative analysis does reveal some areas for improvement, as indicated by occasional moderately negative sentiments. These insights are crucial for refining PCS-AI, ensuring it addresses all student concerns and enhances the user experience.

The integrated analysis demonstrates that PCS-AI v1.0 is a highly effective tool significantly enhancing learning in the Formal Languages and Automata course. The overwhelmingly positive quantitative ratings, supported by qualitative feedback, indicate that students appreciate the tool's functionality, quality, and utility. This positive reception highlights PCS-AI's potential as an asset in educational settings, fostering better understanding and engagement with complex course materials. Continuous improvements based on student feedback will further solidify its role as a pivotal educational tool.

Conclusion

The evaluation of PCS-AI v1.0 in the Formal Languages and Automata course has demonstrated significant positive outcomes, highlighting the awareness and importance of Pre-conceptual Schemas in knowledge representation. PCS-AI v1.0 has highlighted how effectively these schemas can facilitate students' understanding of complex concepts, promoting a structured and comprehensive approach to learning. The high functionality ratings and positive qualitative feedback underline the pivotal role of Pre-conceptual Schemas in enhancing educational experiences.

The benefits of pre-conceptual schemas for students are particularly evident in using PCS-AI v1.0. The tool's ability to generate high-quality responses and support the learning process has been well-received, as indicated by students' overwhelmingly positive quantitative ratings and sentiments. By integrating AI with Pre-conceptual schemas, PCS-AI v1.0 offers a robust framework that aids in the assimilation of abstract concepts, making the study of Formal Languages and Automata more accessible and engaging for students.

Moreover, PCS-AI v1.0's wide range of application possibilities extends beyond the immediate scope of the Formal Languages and Automata course. The tool's versatility and adaptability suggest its potential utility across various educational settings and disciplines. This flexibility opens new avenues for implementing AI-supported tools in diverse academic contexts, enriching the educational landscape.

However, to fully harness the benefits of AI-supported tools like PCS-AI v1.0, addressing and overcoming any existing fears or reservations about their use is crucial. The qualitative analysis revealed some moderately negative sentiments, indicating that while most students are enthusiastic about the tool, concerns still need to be addressed. Promoting a better understanding of AI's capabilities and limitations and providing adequate support and training can help mitigate these fears and encourage more widespread adoption of such tools.

In conclusion, PCS-AI v1.0 has proven to be an asset in the Formal Languages and Automata course, significantly enhancing students' learning experiences using Pre-conceptual Schemas. The positive feedback and high ratings underscore its effectiveness and potential for broader application. Addressing the challenges and fears associated with AI-supported tools will be essential in maximising their benefits and ensuring they become an integral part of modern education.

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