From Classroom to Real-World: University Students' Experience in Learning Solidity and Blockchain

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***Abstract**. Blockchain technology has taken over many business processes today. We find its influence in many real-world use cases such as energy management, healthcare, supply chains, waste management, shipping, insurance, tourism, education and others. Solidity is an object-oriented programming language used to write smart contracts in the Ethereum environment, often utilizing the Remix IDE. Learning how to write smart contracts in Solidity was included in the teaching process at one of the faculties in Croatia, and a survey was conducted among students on the success of knowledge acquisition in the areas of blockchain and Solidity.*

Keywords. Blockchain, Solidity, university, practice.

1 Introduction

The use of blockchain in education has become one of the trending topics in educational technology research. However, few blockchain solutions for education have provided a measurement of impact on student learning outcomes, teaching or administrative processes (Ocheja et al., 2023). The use of blockchain, particularly in the areas of teaching and learning and academic administration, has created space for a new business model in higher education (Brown, 2022). The advantages of blockchain technology, such as decentralization, tamper-proofing, anonymity, traceability, etc., offer the possibility of improving the security of the management of teaching informatization in higher education (Zhang et al., 2020). "Blockchain technology is conducive to protecting online educational resources, strengthening the transparency of online teaching resources, simplifying the copyright transaction process, and thus improving the scientific and technological innovation ability of teachers." (Hao et al., 2023)

Normally, audit authorities and central institutions need more time to carry out operations, which is a time-consuming process. With blockchain technology, we can eliminate the risk of central server failure. The data stored in the blockchain is tamper-proof and cannot be modified once deployed on the blockchain network (Karale & Khanuja, 2019).

The motivation for writing this paper came from the curiosity to evaluate the experiences of university students learning to write smart contracts using the Solidity programming language. The Solidity programming language is used to implement smart contracts on various blockchain platforms, mainly Ethereum. The students wrote smart contracts in the Remix Ethereum IDE development environment. The goal of this research is to investigate students' experiences of learning blockchain concepts and writing smart contracts in the Solidity programming language at a faculty.

The research questions are:

1. How can blockchain technology and Solidity be used in higher education and teaching according to the existing literature?
2. What are the limitations of learning blockchain and Solidity in higher education?
3. What would be the recommendations for improving the quality of blockchain and Solidity teaching according to the research findings?

2 Literature Review

For the literature review, articles were selected from the scientific databases Scopus and Web of Science. Recent articles were selected based on the relevance of the research area using the keywords ("blockchain" OR "Solidity") and "education".

Distributed ledgers and smart contracts are among the blockchain features that could help improve efficiency, security and privacy in the execution of academic administration, particularly in student identification, admissions application processing, degree certification, document authentication and quality assurance (Brown, 2022). The aim of the chapter (Brown, 2022) was to introduce blockchain technology as a framework and show how it can be used in higher education teaching, learning and

administration in times of crisis to effect and manage practical change.

The authors (Nguyen et al., 2023) propose a system for ticket issuance and ticket traceability by applying smart contract technology on the blockchain platform to store, manage and trace the origin of tickets. The system was developed on the Ethereum platform to implement smart contracts and blockchain technologies using the Solidity language. The advantage of blockchain is that "it offers great security by preventing information theft and manipulation." (Nguyen et al., 2023)

In the study (Rosasooria et al., 2020), a blockchain system for electronic voting was developed to detect fraud in voting using the Solidity language. A blockchain e-voting system was proposed that has secure and transparent features for use during the Student Representative Council (SRC) election.

In the paper (Ocheja et al., 2023), the authors present the results of the review of existing visualizations in blockchain and non-blockchain educational technologies and suggest how blockchain tools for education can provide better visualizations to support learning objectives. They also report the results of an initial validation of their proposal with teachers through a qualitative method.

The paper (An et al., 2021) addresses the shortcomings of talent training modes in colleges and universities and proposes a blockchain-based intelligent teaching system for smart education. This system proposes to improve students' practical innovation ability through the comprehensive participation of tutors from school and enterprise in the students' education process.

The authors of the study (Meyliana et al., 2020) attempted to create a process model of the university teaching and learning process. They tried to answer how teaching and learning activities can be supported by blockchain technology. To do this, they used qualitative methods and focus group discussions with 9 universities.

The paper (Chan & Shan, 2022) uses the literature research method, by combining the blockchain education application related literature, summarizes and finds that the current blockchain application mainly focuses on the following aspects of learning process: tracking and analysis, education management and decision-making, open resource sharing, copyright authentication and protection, credit bank and education service supported by blockchain technology, and the future development of blockchain.

The authors (Zhang et al., 2020) sought to explore the application of blockchain in education to improve the practice of the system of teaching informatization management in higher education. They supposed that the security of informatization storage would be ensured, the credibility of data monitoring would be increased, administrative costs would be reduced, and the efficiency of higher education management would be greatly improved if blockchain technology would be used in the system of teaching informatization management.

The research (Liu, 2021) mainly explores and studies the distance education system based on blockchain technology according to the characteristics of blockchain technology. A multi-layer logical structure was designed, and the generation steps of the blockchain in the system and the operation process of the consensus mechanism were analyzed.

The authors (Thompson et al., 2023) present NFTrig, a web-based application developed as an educational tool for teaching trigonometry and blockchain technology. The creation of the application includes front-end and back-end development as well as integration with other external sources such as MetaMask and OpenSea. Key development languages include HTML, CSS (Bootstrap 5) and JavaScript, as well as Solidity for the creation of smart contracts. The technical report describes how the application was created, the requirements of the application and how the smart contract was designed with security aspects in mind.

Studies on the application of blockchain technology in education were analyzed in (Hao et al., 2023), and the influences of the aspects of the application of blockchain technology in education on the sharing of online teaching resources were investigated. Based on the research on blockchain technology, educational applications and the sharing of online teaching resources, the study developed a questionnaire entitled “The influence of blockchain technology application in education on online teaching resource sharing”, which mainly included the following aspects. The first aspect was to measure the educational application of blockchain technology. The second aspect was to measure the online sharing of teaching resources. The third aspect, the descriptive statistics of respondents, mainly included 5 questions: respondents' gender, title, age and colleges/universities, and their familiarity with blockchain technology.

The research (Swati & Nitin, 2023) presents an innovative smart scholarship management system that utilizes blockchain technology. The research presents an Ethereum-based implementation that uses Solidity for backend smart contracts and ReactJS for the frontend. The experimental evaluation validates the gas cost for transaction execution and deployment cost.

The article (Liu & Zhu, 2021) analyses the technical foundations of blockchain and the shortcomings of online teaching and cross-regional teaching in cultural and creative design education. Blockchain technology is used in the management of learning resources, the tracking of learning processes, learning evaluation, the design of learning pathways and teaching management and assessment. The conclusion is that "blockchain technology can effectively optimize the teaching structure and management in cultural and creative design education" (Liu & Zhu, 2021) and promote the adaptation of design education to contemporary development.

The authors (Li & Zhao, 2021) investigated the application of blockchain technology in the Open University's distance learning sector. Their research adopts a hierarchical network architecture and hierarchical storage structure, which has good scalability and node transparency, and supports the user service strategy in large-scale applications.

The article (Li & Wu, 2019) analyses the core technology and the principle of blockchain and presents its advantages for use in the classroom. In the context of educational practise, the authors explain the structure and function of the framework, core components and application modules of the blockchain teaching platform. The research also explains the method of building the blockchain teaching platform and introduces problems and thoughts on blockchain application in school teaching.

The research (Widjaja et al., 2020) attempts to look for outstanding issues, current trends, benefits and challenges of blockchain technology in the education sector and the impact of blockchain technology on the important elements in universities such as people, processes and technology. The research is conducted through a systematic literature review to get a complete picture of blockchain technology in universities. The results show that the people, processes and technology aspect of the university has a direct impact, but the impact of blockchain technology brings many benefits not only to the students but also to the institution. Efficient processes, secure data, reliable and trustworthy information could be another value for the university.

The advantages of using blockchain in education and administration are seen in the existing literature primarily in the security of the system against unauthorized manipulation and data theft. In addition, the use of smart contract technology for data storage, management and monitoring was noticed. Finally, the studies attempted to answer how teaching and learning activities can be supported by blockchain technology.

3 Methodology

In 2024, writing smart contracts in the Solidity programming language was taught for the first time at one of the faculties in Croatia. Writing smart contracts was taught by students in two related courses at the same faculty. These two courses were related to the digital business. One of the courses was conducted as part of the undergraduate vocational study programme and the other as part of the graduate study programme.

During the semester, students had the opportunity to go through the material on writing smart contracts in Solidity in about ten lessons, starting from learning the basics of the programming language to more complex tasks that occur in the real world of blockchain. The lessons were held in the form of exercises on the computers and the lectures. The basic concepts of blockchain and digital business were taught in the lectures, and the programming of smart contracts in Solidity was taught in the exercises on the computers. Students first learned the basics of programming in the Solidity programming language and then worked on real examples of transactions that occur in the blockchain. In addition, the students had the task of independently creating a Solidity project by researching specific real-world examples and programming them independently.

For research purposes, a survey was conducted among students who were studying the programming of smart contracts in the Solidity. From 40 full-time students, attended the undergraduate vocational study (UVS) program, 36 of them participated in the survey. From 114 full-time students, attended the graduate study (GS) program, 85 of them participated in the survey. Participation in the survey was anonymous and voluntary. The respondents of the survey were IT students.

The survey was conducted using Google forms and the questions were mainly aimed at assessing the satisfaction or success of the materials adopted and the application of the knowledge acquired. Responses were recorded via online Google forms on a scale of 1 to 5, with 1 representing "least satisfaction" and 5 representing "greatest satisfaction", i.e., "excellent performance". After completing and submitting the surveys, the Google forms summarized the results in columns for each question. More specifically, the percentages for each grade were calculated for each question. The students filled out the survey at the end of the semester. The survey questions were structured as follows: First, demographic data such as age of the respondents were examined. Then, questions about previous experience with programming were asked. This was followed by questions about knowledge of blockchain technology and the Solidity programming language, examining respondents' knowledge of these topics before the course and their understanding of blockchain and Solidity concepts after the course they had attended. Questions were then asked about the learning experience, in which respondents were asked about learning challenges. After the learning experience questions, respondents were asked questions about the practical application of Solidity. The last group of questions related to the respondents' future interest in the further application of knowledge in the field of blockchain and Solidity.

4 Results of the survey

This chapter describes the results of an online survey conducted among students participating in courses about blockchain and writing Solidity smart contracts. The results of the survey showed that the majority of respondents, 97% from the UVS program and 98% from the GS program, were between 18 and 25 years old. The remaining respondents were between 25 and 30 years old.

According to the results, the respondents of both study programs (UVS and GS) stated that they already had experience with programming in the following languages: C++, C, C#, Python, Java and JavaScript. Considering the similarity of Solidity with the listed programming languages, this result can be considered very significant as it means that it was easier for the students to acquire the knowledge of programming smart contracts in Solidity. The comparison of the results of knowledge about blockchain technology and the Solidity programming language from two study programs can be seen in Table 1.

Table 1 Knowledge of blockchain technology and the Solidity programming language: a comparison of the results of two study programs

Question	Undergraduate vocational study (UVS) programme	Graduate study (GS) programme
Familiarity with blockchain technology before the class?	Insufficiently- 22,2%; sufficiently – 44,4%; good – 19,4%; very good – 13,9%; excellent – 0%.	Insufficiently- 27,1%; sufficiently – 43,5%; good – 21,2%; very good – 7,1%; excellent – 1,2%.
Familiarity with Solidity programming language before the class?	Insufficiently- 86,1%; sufficiently – 11,1%; good – 0%; very good – 2,8%; excellent – 0%.	Insufficiently- 92,9%; sufficiently – 3,5%; good – 1,2%; very good – 1,2%; excellent – 1,2%.
Level of understanding of blockchain concepts after attending the class on this topic?	Insufficiently- 0%; sufficiently – 2,8%; good – 27,8%; very good – 61,1%; excellent – 8,3%.	Insufficiently- 1,2%; sufficiently – 2,4%; good – 30,6%; very good – 61,2%; excellent – 4,7%.
Level of understanding of writing smart contracts in Solidity after attending the class on this topic?	Insufficiently- 0%; sufficiently – 13,9%; good – 33,3%; very good – 47,2%; excellent – 5,6%.	Insufficiently- 2,4%; sufficiently – 3,5%; good – 44,7%; very good – 40%; excellent – 9,4%.

We knew that the responders were familiar with the C programming languages, Python, Java and JavaScript before this course, but what about blockchain technology and the Solidity programming language? According to Table 1, we can notice how the understanding of blockchain concepts increased among students in both study programs after participating in the courses. In addition, students had little or no familiarity with the Solidity programming language before the course. After the course, the majority of respondents in both study programs feel that they have a good or very good understanding of writing smart contracts in Solidity. It is interesting to note that 5.6% of students on the UVS program and 9.4% of students on the GS program believe that they have an excellent command of writing smart contracts. It can be assumed that these are students who may be interested in applying programming using Solidity in their future careers or simply continuing their personal development in this direction.

Table 2 A learning experience: a comparison of the results of two study programs

Question	Undergraduate vocational study (UVS) programme	Graduate study (GS) programme
Were there any aspects of learning the Solidity language that you found challenging?	Yes – 19,4% No – 80,6%	Yes – 17,6% No – 82,4%
What resources have helped you the most in mastering the Solidity language?	Teaching material from the course page + exercises on the computer: 77,8%, Online content: 22,2%.	Teaching material from the course page + exercises on the computer: 64,7%, Online content: 32,9%, Something else: 2,4%.
Evaluate the effectiveness of the teaching methods and materials used in the course (exercises on the computer, project assignment, etc.) in mastering Solidity and blockchain:	Insufficiently- 0%; sufficiently – 0%; good – 16,7%; very good – 50,0%; excellent – 33,3%.	Insufficiently- 2,4%; sufficiently – 7,1%; good – 21,2%; very good – 40,0%; excellent – 29,4%.

In the survey, respondents were asked if there were any aspects of writing smart contracts in Solidity that they found challenging. If so, respondents were asked to explain these aspects. Most responded that it took time to understand the differences of the Solidity language compared to other languages. They responded that once you understand how the logic of smart contracts works conceptually, "everything works smoothly". They also responded that understanding some of the specifics of the language took a little more time. In addition, some respondents stated that they were generally less good at programming or simply did not have enough experience with programming. In general, the answers were along the direction that you first have to catch the differences compared to other programming languages. According to Table 2, the majority of respondents, 77.8% in the UVS program and 64.7% of respondents in the GS program, declared that the teaching material from the course page, including the exercises on the computer, helped them the most in learning the Solidity language, and then the online content. To learn Solidity, 22.2% of responders in the UVS program and 32.9% of responders in the GS program used online content. In addition, respondents rated the effectiveness of the teaching methods and materials used in the course for mastering Solidity and blockchain very highly. As many as 50% of respondents of the UVS program consider the methods and materials are very good and 33.3% consider the methods and materials are excellent. For the GS program, 40.0% of respondents believe that the methods and materials are very good and 29.4% consider them to be excellent.

Table 3 Practical use of Solidity and blockchain knowledge: a comparison of the results of two study programs

Question	Undergraduate vocational study (UVS) programme	Graduate study (GS) programme
Have you had the opportunity to use your Solidity skills outside the classroom (e.g., on your own projects)?	Yes - 19,4%, No – 80,6%	Yes – 20,0%, No – 80,0%
How ready do you feel to apply Solidity in the real sector?	Insufficiently- 0%; sufficiently – 27,8%; good – 44,4%; very good – 27,8%; excellent – 0,0%.	Insufficiently- 9,4%; sufficiently – 29,4%; good – 47,1%; very good – 12,9%; excellent – 1,2%.

Regarding the practical use of Solidity and blockchain knowledge, the majority of responders on both study programs stated that they did not have the opportunity to apply their Solidity skills outside of the classroom, e.g., on their own projects or in a real sector. However, according to the results from Table 3, the majority of responders in both study programs feel sufficiently prepared or ready to apply their knowledge and skills in the real sector. It is assumed that these are students who are willing to work in the real sector, where applications are developed in blockchain, and who are familiar with programming in Solidity after the course.

Table 4 Future interests for using Solidity and blockchain: a comparison of the results of two study programs

Question	Undergraduate vocational study (UVS) programme	Graduate study (GS) programme
How interested are you in further projects related to blockchain technology and Solidity?	Insufficiently- 2,8%; sufficiently – 16,7%; much – 38,9%; very much – 27,8%; the most – 13,9%.	Insufficiently- 17,6%; sufficiently – 21,2%; much – 38,8%; very much – 18,8%; the most – 3,5%.
Assess how knowledge of blockchain technology and Solidity will benefit your future career or profession.	Insufficiently- 0%; sufficiently – 11,1%; good – 47,2%; very good – 38,9%; excellent – 2,8%.	Insufficiently- 11,8%; sufficiently – 29,4%; good – 36,5%; very good – 15,3%; excellent – 7,1%.

Table 4 shows that respondents in the UVS program are more interested in participating in future projects related to Solidity and blockchain than students in the GS program. Furthermore, it was found that the same respondents were more likely to see the benefit of knowing a new programming language for their future career and/or profession. The reason for this could be that students in the GS program have already found an

interest in another field during their studies or do not believe that they will need programming skills in the future.

Most respondents in both programs believe that knowledge of blockchain technology and Solidity will benefit them in their future career or profession. As many as 47.2% of respondents in the UVS program believe this knowledge will benefit them good, and 38.9% of respondents believe it will benefit them very good. 36.5% of respondents in the GS program believe that this knowledge will be of good use to them, 15.3% believe that it will be of very good use to them, and 7.1% believe that knowledge about blockchain and Solidity will be of excellent use to them.

5 Limitations of learning blockchain and Solidity in higher education

The limitations of the learning outcomes may be hidden in the fact that writing smart contracts in Solidity has not yet reached its full potential as it is a new technology, so students do not yet realise the importance of knowing the new technology. Students are used to the knowledge taught at university, so it can be more difficult for them to perceive new knowledge and new technologies with which they were previously unfamiliar. It is assumed that as writing smart contracts in Solidity and knowing how transactions in blockchain work become more dominant in the market, students will also feel the need to keep up with the times and technologies.

It should also be noted that many students do not have an affinity for programming, so learning experience surveys may show weaker results when respondents are asked about their future interests. Most students may not want to programme in the future and see their professional career in other fields.

The limitations of learning blockchain and Solidity are seen in several aspects: students should have developed the basic concepts of object-oriented programming. They should also be more motivated to learn a new programming language. Prior knowledge about the blockchain technology would also be helpful. It would be scientific interesting to repeat this type of survey in the future with other students to see if students have recognized the importance of knowing another programming language over time and how blockchain transactions work.

6 Recommendations for improving the quality of blockchain and Solidity teaching

In order to successfully teach blockchain and Solidity, it is necessary to keep up with the times and monitor the projects appearing on the market and the private sector's need for people who have a basic skill of blockchain and are able to independently create smaller applications such as smart contracts in Solidity.

We believe that we offered a lot to the students during the course, because we taught them the basics of the programming language, we taught them to create real smart contracts for sending transactions on the blockchain as they usually occur in real sector, and the students created independent projects in which they were to show their autonomy, the ability to create "real world" smart contracts and present what they had learned. The experiences we gave them were theoretical and practical in nature.

The recommendations that we would give are in the direction of practical examples and independent work of the students in the form of projects, with a previous good theoretical background and processed examples from “real world”, which the students go through together with the teacher. In addition, students can be involved in projects in which the university works together with the real sector or market. This allows students to get to know the experience of working in private companies during their education and establish contacts with individuals who conduct blockchain transactions as part of their daily business.

7 Conclusion

Understanding how to write smart contracts in Solidity is significant for university students due to its relevance in emerging technologies, innovation, and practical application. Blockchain technology, particularly the Ethereum platform, is rapidly gaining traction across various industries, and Solidity is the primary language for developing smart contracts on this platform. Mastery of Solidity ensures that students are well-versed in cutting-edge technology, enhancing their competitiveness in the job market. Thus, proficiency in Solidity and smart contract development equips students with valuable skills that are essential for their future careers in a technology-driven society.

The goal of this research was to investigate students' experiences of learning blockchain concepts and writing smart contracts in the Solidity programming language. Furthermore, based on the research findings, the limitations of learning blockchain and Solidity in higher education were identified and recommendations to improve the quality of blockchain and Solidity teaching were proposed. The potential impact of this research in the field of educational technology is to improve and, if necessary, adapt the teaching material to the needs of the students and to recognize the purpose and importance of the course in today's era of rapid changes in the IT sector and ICT. In the course we try to meet not only the needs of students but also those of employers who are looking for workers with specific, possibly rare, skills. Our task is to identify such employers and provide them with a workforce that meets their business needs.

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