BlueVision: A Visual Tool for Exploring a Blockchain Network

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***Abstract*—Despite the growing interest in distributed ledger technology, many data visualizations of blockchain are limited to monotonous tabular displays or overly abstract graphical representations that fail to adequately educate individuals on blockchain components and their functionalities. To address these limitations, it is imperative to develop data visualizations that offer not only comprehensive insights into these domains but education as well. This research focuses on providing conceptual understanding to the consensus process that underlies blockchain technology. This is accomplished through the implementation of a dynamic network visualization and an interactive educational tool called BlueVision. Further, a controlled user study is conducted to measure the effectiveness and usability of BlueVision. The findings demonstrate that the tool represents significant advancements in the field of blockchain visualization, effectively catering to the educational needs of both novice and proficient users.**

***Index Terms*—Blockchain; Consensus; Visualization;**

I. INTRODUCTION

Blockchain technology has been steadily increasing in popularity since the inception of Bitcoin in 2009 [1]. In essence, a blockchain acts as an immutable ledger stored within multiple nodes on a decentralized peer-to-peer network. While the most popular application of blockchain currently is cryptocurrency, the basic mechanics of blockchain were introduced almost 20 years prior to Bitcoin's release [2]. Besides cryptocurrency, blockchain holds numerous potential groundbreaking applications; ranging from supply chain management, digital verification, voting authenticity, internet of things, medical security, central bank digital currencies, and more. These potential applications dramatically increase the chance of people interfacing with blockchain in their everyday lives, and calls for a more comprehensive understanding of the technology.

Even with blockchain's increasing popularity, most of the world lacks knowledge in even the most basic blockchain components and their functionalities. A recent study showed that only 25% of adults in the U.S. have any idea of what blockchain is, and only 18% have used blockchain in any medium [3]. The same study also revealed that 62% of adults surveyed believe that blockchain is the same as cryptocurrency, which is a major concern when considering that 75% of Americans are not confident in cryptocurrencies' safety and reliability [4]. If blockchain is to flourish in society, individuals must cultivate familiarity and trust in its usage and applications. This is where educational visualizations of blockchain data can make an impact and bridge the gap between the esoteric nature of blockchain and the everyday user of the technology.

Standard practices in blockchain visualization typically involve scraping data from the blockchain and presenting these visualizations to the user as a 'blockchain explorer.' This term originated from Blockchain Explorer, which was the first tool to visualize blockchain data. [5]. Released in 2011, this tool displayed information about recent Bitcoin transactions including their senders and recipients, the hash of the most recent block, block size, and block reward. This practice became common in the ecosystem with some of the most popular tools such as Etherscan [6] and XRPScan [7] presenting information about the Ethereum and XRP blockchain in a similar manner, respectively.

Many blockchain data visualizations are beautiful instances of applying animations and visual effects to blockchain data, however they do not thoroughly educate new users (NUsers) nor experienced users (EUsers) of distributed ledger technology on the processes occurring within the ledger. NUsers need to be properly educated on the hierarchy of the blockchain, which follows the structure: blockchain, blocks, transactions, and addresses. EUsers typically understand this hierarchy, but find common ground with NUsers in the misunderstanding of the peer-to-peer network's core characteristics: the relationship between the nodes and the ledger, the nodes' consensus mechanism, and decentralization of nodes. For example, BitcoinCity and Bitcoinrain [8][9] visualize the Bitcoin ledger in unique ways by presenting transactional data in analogous fashion. These visualizations are interesting to view, but they do not provide educational material for NUsers or sufficient information for EUsers. In contrast, Bitfeed [10] accurately displays the transactional data on Bitcoin by packing transac-

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tions into a large block with interactive capabilities to view the data, but the visualization neglects explaining this data to NUsers. Bitnodes [11] is an example of a popular visualization depicting node activity, however it simply details a heat map of nodes' geographical location, failing to portray the node-ledger relationship, consensus mechanism, and decentralization of nodes to both types of users.

The effective implementation of blockchain visualization encounters challenges in two primary aspects: the prerequisite knowledge necessary to comprehend visualizations and the intricate characteristics of the blockchain that need to be represented. When NUsers engage with a blockchain visualization, they are confronted with a multitude of unfamiliar terms and concepts that are completely foreign. As NUsers navigate through a visualization, they must grapple with concepts regarding cryptography, consensus mechanisms, decentralized networks, and the blockchain itself. NUsers also encounter initially nonsensical terms such as block, transaction, address, hash, and node. This influx of new information presents a significant cognitive challenge, as NUsers must not only comprehend the visual representation but simultaneously develop a foundational understanding of the underlying principles. EUsers tend to have a solid grasp of decentralized finance applications in distributed ledger technology, which are most commonly represented by blockchain visualizations. Even so, these users can still benefit and learn from exploring visualizations that provide insights into the underlying mechanisms of a blockchain network. By delving deeper into the intricacies of consensus mechanisms and information flow within the network, EUsers can enhance their expertise, identify potential optimizations or vulnerabilities, and make informed decisions in utilizing blockchain technology.

This research proposes to introduce data visualizations on blockchain that overcome the challenges that NUsers and EUsers face whenever utilizing the aforementioned blockchain visualizations. A novel blockchain explorer is designed, called BlueVision [12], that visualizes the processes within the open-source blockchain network BlueChain [13] with the purpose of educating both NUsers and EUsers on components and functionalities of distributed ledger technology. BlueVision is an online tool that boasts user configurability, interactive capabilities, real-time visualizations, and sequential lessons of the BlueChain consensus protocol. BlueVision's functionalities can be split into two main pages, the live network page and the consensus education page. After user configuration of the BlueChain network, users are taken to the live network page that visualizes live data from the nodes on the BlueChain network. The live network page uses data abstracted from the network to dynamically visualize nodes and their connections, messages between nodes, the state of the ledger, and transactions on the network. The live network page allows for interaction with any of the blocks in the chain, in which users can select a given block to launch the consensus education page. The consensus education page uses network data abstracted from the specific block chosen in order to provide a complete guided tutorial for the creation and consensus for the next block in the ledger chronologically. This page features interactive animations under user control, supplemented by informative textual descriptions and educational visualizations. In combination, these pages provide a comprehensive exploration of the BlueChain network while simultaneously educating both NUsers and EUsers in blockchain subjects.

This work makes the following contributions to the field of blockchain data visualization:

1) *A tool for visually teaching about blockchain.*
2) *A user study of the effectiveness of the tool.*
3) *A tool to explore different blockchain traces for research purposes.*

While this research makes valuable contributions, it is important to acknowledge certain limitations. For one, the educational component primarily focuses on the consensus protocol within distributed ledger networks and may not provide comprehensive education on other crucial aspects of blockchain technology. As a result, users may have a limited understanding of broader blockchain concepts beyond the consensus mechanism. This research also assumes that every node in the network visualized behaves honestly and efficiently, overlooking the possibility of malicious behavior or network disruptions. By presuming a flawless system without accounting for potential issues or vulnerabilities, the research fails to address real-world scenarios where nodes may deviate from expected behavior. Finally, this tool is currently limited to applicability of the BlueChain network. At the current state of research, this tool cannot be simply applied to other blockchain networks. These limitations highlight the need for future research endeavors to explore and educate users on various dimensions of blockchain technology within different blockchain networks while also accounting for potential security risks and network disturbances.

In summary, this paper presents BlueVision, a novel blockchain visualization tool designed with an educational and user-centric approach. It features a combination of dynamic, interactive, and in-depth educational elements, employing live blockchain data to enhance users' comprehension of the consensus mechanism and network activities within blockchain technology.

II. Related Work

The consensus protocol plays a vital role in blockchain, and researchers are continually exploring various proposed consensus mechanisms to identify effective attacks, defense methods, and security models [14]. Through this exploration, researchers tend to agree that there is no universally superior consensus mechanism. Instead, the optimal choice of a consensus protocol is dependent upon its specific application scenario [14]. In light of this, Xiao et al. [15] focuses on providing a comprehensive review of state-of-the-art blockchain consensus protocols, comparing them in relation to fault tolerance, transaction processing capability, and a five-component framework. Zhou et al. [14] analyzes both traditional and blockchain consensus mechanisms and categorizes them into four "beginner-friendly" types, specifically crash fault tolerance (CFT), Byzantine fault tolerance (BFT), proof of something (PoX) series, and hybrid consensus mechanisms. Some researchers classify the appropriate consensus mechanism for an optimal blockchain solution as an inherent tradeoff between scalability and performance [16, 17]. For example, Vukolić [16] contrasts proof of work (PoW) and BFT consensus mechanisms, noting PoW-based blockchains offer desirable node scalability with poor performance, while BFT-based blockchains offer optimal performance with limited scalability. Similarly, Nguyen et al. [17] categorizes blockchain consensus mechanisms into proof- and voting-based governance protocols, the first being applicable in scenarios requiring high scalability and the latter being optimal for a limited number of nodes. Furthermore, Milutinovic et al. [18] proposes a novel proof of luck consensus mechanism to address the impracticality of high-latency transaction validation in PoW-based blockchains.

While researchers have started exploring visualization techniques of various aspects of blockchain, many of these works are challenging to comprehend and provide limited insights into the inner workings of blockchain consensus mechanisms. Porat et al. [19] implements the PoW consensus protocol and provides a static visualization to monitor the network and the ledger. Ambrosini et al. [20] uses a color-coded visualization of the last two blocks in various nodes of the Bitcoin network to visualize consensus degradation. Baldouski et al. [21] reviews methods for debugging voting-based consensus mechanisms within decentralized networks, utilizing Grafana plugins to develop an animated visualization for researchers and developers to test these networks. Peryt et al. [22] visualize malware distribution networks using dynamic behavioral graphs to reveal their topological structure, including persistent subnetworks and individual top-level domains that are critical to a successful operation of the network.

In order to provide a better understanding of blockchain technology, design researchers have implemented various visualizations which tend to focus on cryptocurrency transaction data. For example, Liu et al. [23] informs readers that existing research on cryptocurrency transactions using data mining techniques can be categorized into three groups, namely transaction tracings and blockchain address linking, analysis of collective user behaviors, and the study of individual user behaviors. An enumeration of visualizations exist for these three domains, and they may be classified by either static or dynamic graphs. Further, Wu et al. [24] narrows the search to an analysis of works that study cryptocurrency transactions from a network perspective in terms of network modeling, network profiling, and network-based detection. Tharani et al. [25], proposes algorithms to extract transaction-related data from the Bitcoin and Ethereum networks. From the data, three types of graphs were generated, specifically a transaction graph, an address graph, and a money flow graph, which were used to visualize patterns of illicit transactions. Zhong et al. [26] proposes an online cryptocurrency viewing tool, called Silkviser, and analyses its effectiveness through a controlled user study.

Tovanich et al. [27] introduces how current blockchain visualizations have been used by researchers and practitioners in various fields, such as economics, computer science, and public audiences. The authors observed that among the 76 visualization sources they reviewed, Bitcoin data was the most commonly visualized. They also identified a notable scarcity of sources dedicated to visualizing other application domains, such as smart contracts, consensus, or network activity. In their research, the authors put forward suggestions for future work, emphasizing the needed development of advanced interactive tools that facilitate visual comparisons–aiming to establish connections between different perspectives and generate more comprehensive insights on the entirety of the blockchain. This highlights the pressing need for an in-depth educational tool in one of the application domains mentioned earlier. Existing visualization tools primarily focus on presenting basic blockchain statistics to viewers, rather than effectively educating them about the underlying data being presented. For example, BitConduite [28] analyzes various entity groups in Bitcoin and displays them in multiple respective graphical views. Blockchain.info [29] provides charts showing aggregated statistics of the Bitcoin network. Other tools show transaction data in an animated manner, such as BitListen [30] which presents transactions as animated bubbles producing musical notes. While all of these examples provide neat and intricate visual representations, they require a viewer to have previous knowledge of blockchain technology to comprehend the importance of the data and to effectively deduce their own opinion.

The limitations identified in the previous studies can be summarized in three facets. First, existing visualization tools primarily focus on visualizing basic blockchain data in textular and tabular format, such as transaction and block data. Second, numerous visualizations tend to be inherently challenging to comprehend. For instance, they may present information that is overly ambiguous or fail to provide adequate justification for each component. Third, previous studies primarily target users with a pre-existing background in related domains, such as computer science or finance. The proposed tool aims to address these limitations by leveraging innovative approaches and fostering further advancements in the field of blockchain visualization.

III. Background and Proposed Framework

A. Consensus Algorithms

The rise of blockchain networks have prompted the use of diverse consensus protocols, each tailored to different contexts. Proof-of-Work and Proof-of-Stake tend to be cited as the two most popular consensus mechanisms in distributed ledger networks. Proof-of-Work typically refers to the consensus algorithm in which nodes on the network solve complex mathematical problems in order to construct blocks. The nodes that correctly solve these problems and append blocks to the ledger are gifted rewards in response to their successful behavior in progressing the network's state. Proof-of-Stake generally points to the consensus mechanism in which nodes

Table I: Summary of closely related works categorized by their target user and their contributions (to both blockchain research and blockchain visualizations).

Related Works	**Target Users**		**Visualization Type**			**Blockchain Data**					
	Novice	Experienced	Interactive	Static	Live	Consensus Mechanism	Transactions	Blocks	Addresses	Network Activity	Others
Baldouski et al. [21]		✓	✓			✓				✓	✓
BitConduite [28]		✓	✓	✓			✓		✓		✓
BitListen [30]	✓				✓		✓				
Blockchain.info [29]		✓		✓			✓				
Liu et al. [23]	✓						✓		✓		✓
Porat et al. [19]		✓		✓						✓	✓
Tovanich et al. [27]	✓		✓	✓			✓	✓	✓	✓	✓
Xiao et al. [15]		✓		✓		✓					
Zhong et al. [26]	✓	✓	✓				✓	✓	✓		
Zhou et al. [14]	✓			✓		✓					
This Paper: BlueVision	✓	✓	✓		✓	✓	✓	✓		✓	

are selected to create blocks based on their delegation of tokens to the network. These tokens are used to help validate new blocks and append them to the ledger. These consensus algorithms do not fit all needs for certain networks, and there are other protocols used across different networks; including, but not limited to: Proof-of-Authority, Proof-of-Space, Proof-of-Activity, and Quorum-based consensus.

BlueVision visualizes the processes within BlueChain, which utilizes a quorum-based consensus algorithm in constructing blocks for the network. Quorum-based consensus is a prevalent approach to consensus and governance within distributed, decentralized blockchain networks. In a quorum-based consensus mechanism, a subset of nodes are selected in order to validate and construct blocks for the network. This quorum is typically a predetermined percentage of nodes on the network that solidify connections amongst one another in order to progress the network's ledger. The key principle underlying quorum-based consensus is that a consensus decision is valid only if it is supported by a majority or supermajority of nodes within the designated quorum. This approach ensures that decisions are made with sufficient governance and safeguards against the influence of malicious or faulty nodes. By requiring a quorum, the protocol enhances the network's resilience to attacks, enhances its overall fault tolerance, and drastically improves its scalability.

In the context of BlueChain, quorum nodes are randomly selected based off the previous block in the network. Block data from the previous block is taken and hashed by the network. This block data consists of the transaction list, the hash of the previous block, and the block's identification chronologically. The network then passes this hash as a seed into a random number generator, producing the quorum members for the network in constructing the next block. This process ensures unpredictability, fairness, and security in the selection of quorum nodes.

B. Motivating Scenario

BlueChain is a decentralized, distributed blockchain network and research framework designed to assist researchers engaged in blockchain solution development. BlueChain was developed for the purpose of education in blockchain technology. Utilizing BlueChain offers several advantages, including its user-friendly configurability, comprehensible code base, and a versatile framework suitable for multiple use cases. Additionally, BlueChain facilitates the acquisition of real-world data, enabling researchers to conduct experiments beyond simulations and obtain authentic results.

Prior to this research, BlueChain lacked a blockchain explorer and was limited to command line output in order to visualize processes within the network. This output fell significantly short in educating NUsers about the components of blockchain technology, while simultaneously failing to provide the in-depth data required by EUsers. Consequently, the user experience for both types of users was both unengaging and insufficient, offering little in terms of comprehensive education or analytical depth for both user categories.

The authors of this paper were commissioned by Boise State University, the network's genesis location, to create a blockchain explorer for the network. After thorough research, it was decided to build a tool that transcends the BlueChain's developer audience. The objective was to create an inclusive, versatile blockchain explorer that could offer value to all BlueVision users, regardless of their experience level or technical skills. The research endeavors to create a comprehensive educational tool, pushing beyond the conventional boundaries of blockchain explorers to foster deeper understanding and engagement for any user.

C. Data Abstraction

In order to visualize the proper mechanics of the network and adhere to the goals of the visualizaiton, four types of data files were extracted from the BlueChain network. In order to obtain these data files, the BlueChain code base was directly modified to output the data needed as the following JSON object files.

Nodes: The nodes.json file encompassed all essential information for each full node within the BlueChain network, including the nodes' IDs (port numbers) and their respective target connections. To obtain this data, each node was programmed to record their ID and connections to the nodes.json file at the time of their instantiation.

Messages: The messages.json file served as a comprehensive log of all communications transpiring within the network. Specifically, it captured every message that was sent and received among all full nodes. To facilitate this, each node documented its activities in the json file each time it transmitted a message. The message details included message type, sender, and recipient, for each json object. The variety of message types encompassed within this file included 'transaction', 'quorum', 'mempool', 'sign block', 'send block', and 'ping'.

Network: The network.json file encapsulates a full-scale view of the network's activity at each block. The structure of the file reflects key data points associated with each block, providing a comprehensive snapshot of the network status at the point of each block's creation. Each entry chronologically designates the block's ID, its unique hash, the participating nodes in the quorum, and the identifiers for transactions included in the block. Additionally, the file provides a count of transactions for each block and an overview of unconfirmed transactions, the mempool, that were present at the time of the block's formation. This snapshot view of each block's creation enables a thorough exploration and analysis of network interactions and transactions, contributing to the understanding of BlueChain's operational dynamics.

Transactions: The transactions.json provided a detailed account of the decentralized finance (DeFi) transactions submitted by a light node on the BlueChain network. To construct this, the light node was programmed to record its generation and submission of transactions to the json file, recording the transaction hash, the sender's and recipient's addresses, and the transaction amount. The addresses represented different light nodes participating in the transaction, while the amount specified the value transferred in each transaction. These transactions served as the driving force behind the network's block creation and its overall progression.

D. Design Principles

To ensure the effective implementation of BlueVision, three distinct design principles were formulated and adhered to during its implementation.

Design Principle 1 (DP1): In order to stimulate learning and curiosity in both NUsers and EUsers, BlueVision should display real-time data visualization boasting interactive capabilities from the BlueChain network. Providing a dynamic experience will captivate users to delve further into the BlueVision tool, enhancing their education in blockchain technology.

Design Principle 2 (DP2): The design of BlueVision must allow users to navigate through the consensus mechanism of BlueChain at their own discretion. With the capability to step through the consensus protocol at their own pace, users will gain a more streamlined understanding in the processes of this protocol and the characteristics of blockchain as a whole.

Design Principle 3 (DP3): BlueVision must facilitate a high degree of user configurability in interfacing with the BlueChain network. By enabling users to customize the network according to their preferences, the tool promotes a unique, non-repetitive experience that can illuminate the separate behaviors in blockchain systems based upon different configurations.

IV. BlueVision Design

The following subsections present a comprehensive overview of the design of BlueVision, along with detailed descriptions of its Live Network and Educational components. Additionally, this section delves into the specifics of each page within the interface and provides insights into the implementation of the visualization elements.

A. Intro and Configuration

The initial phase of user experience with BlueVision focuses on a welcome page followed with a configuration page thereafter. The welcome page provides relevant background about the BlueChain network and an over-arching view of tool's visualization methods. This page also offers a "Get Started!" prompt that allows the user to progress to the configuration page. In line with DP3, the configuration page for BlueVision provides users with the flexibility to tailor the network according to their preferences. The page also provides insights into how various configuration properties are determined based on the user's input. The user chooses the number of nodes they wish to visualize, with the moderator's verbal guidance suggesting a range of 20 to 50 nodes for an optimal balance between clarity and complexity. Once users specify their desired node count, they could then initiate the network, which ran locally on their device, with light nodes submitting transactions concurrently. This activation transitions the user to the live network page, presenting them with their first encounter of the network visualization.

B. Live Network

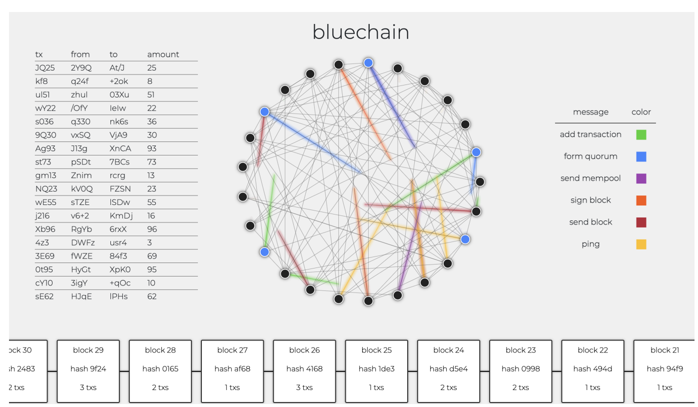

Figure 1: Live Network page design

Circular Network Layout and Messages. The live network page presents an interactive circular layout, providing a visual representation of the ongoing network activity within BlueChain. A circular layout mirrors the decentralization inherent in BlueChain, emphasizing equality of nodes, and ensuring that no single node appears more prominent or authoritative than another. It visually communicates the connectivity of the system while highlighting the democracy within the network. This choice not only ensures an accurate representation of BlueChain itself but also reinforces the fundamental principles of blockchain technology to those engaging with the visualization. Each participant node is depicted as a circle, and nodes belonging to the quorum are distinguished by a blue fill, which will continuously change as each block is added to the network. Connections between nodes are visually represented by lines, offering users a clear understanding of the network's topology. In accordance with DP1, users can hover over individual nodes to access information, such as the node's unique ID number and its specific connections to other nodes within the network. Building upon DP1, the live visualization presents a dynamic and engaging display, featuring vibrant animations representing various messages types. These animations are activated whenever transmissions occur between nodes, enhancing both the clarity, interactivity, and synchronicity of the visualization. The messages to colors map is outlined in a key located to the right of the graph, utilizing the ROYGBIV color scheme to ensure maximum clarity and ease of interpretation for the visualization. For instance, the color green represents the communication of a transaction being added, symbolized by a green "light" traveling from one node to another. Additional messages showcased in the visualization include "form quorum", "send mempool", "sign block", "send block", and "ping". These messages are authentic, real-time transmissions that occur between the network's nodes; simultaneously serving as a high-level representation of the consensus protocol within BlueChain. The live visualization gives users a firsthand look into how the network talks and works together to add new blocks to the ledger. More than just showing flow of data, it gives users the impression that the network is biotic and constantly active. This makes learning about blockchain more engaging, and encourages users to progress in their experience with BlueVision.

List of Transactions. In the Live Network page, the left-most section features a tabular representation presenting a list of all transactions submitted on the BlueChain network. This table provides users with details regarding each transaction, including its unique identifier (ID), source account, target account, and transaction amount. The table is designed to prioritize the latest transactions, placing them at the top for easy visibility. However, users retain the flexibility to navigate through the transaction history with the capability to scroll down the table to access all previously recorded transactions. This continuously updating visualization ensures users can easily follow along as transactions are submitted, exchanged among nodes, and eventually grouped into blocks to be added to the ledger.

The Ledger. The lowermost segment of the Live Network page presents a comprehensive view of the ledger, which is distributed and stored on every node within the network. As new blocks are generated, they appear on the screen sequentially added from the left side, with lines connecting each block conveying the chain attribute and immutability of the ledger. Each block in the ledger is accompanied by crucial information, including its ID, a hash pointer pointing to the preceding block in the chain, and the count of transactions contained within that particular block. Following all three design principles, the ledger's purpose extends beyond mere display, as it serves as the gateway to the consensus education aspect of BlueVision. Users are encouraged to actively engage with the ledger by interacting with the displayed block of their choice. Through a simple click, users can gain access to the educational component of BlueVision, by the dawn of the consensus protocol page. The page will be tailored to the specific block chosen, and will only bring about network information that is relevant to the selected block.

Additional User Interface Elements. When referencing Figure 1, as well as all subsequent figures illustrating the website components, it is important to note that the depicted user interface (UI) is a focused perspective from the user's point of view. Certain elements such as the navigational header are omitted from the captured UI for the sake of spatial clarity in this paper. In the context of the Live Network page, the navigational header provides users with an opportunity to quickly access information regarding all three of the aforementioned segments of the Live Network. The access to this information not only boosts user confidence in their understanding of the displayed content but also ensures that in-depth explanations of the visualization are just a click away, should they be sought.

C. Educational Tool

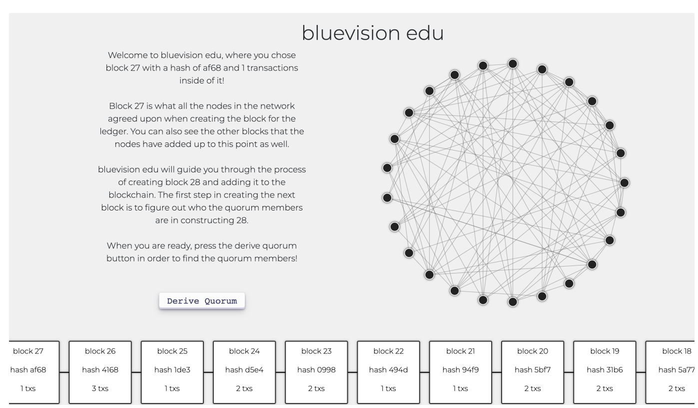

Figure 2: BlueVision Edu page

Education page design. In the Educational page, the introductory display and all following animations adopt a consistent layout where the left side of the screen presents informative text that explains the animations displayed on the right. Furthermore, the bottom section of the screen displays the ledger up to the user's selected block, effectively representing the network's state at their given selection. The informative text on the left details each step in the consensus process, chronologically. To navigate through these steps, users will press the corresponding button located beneath the text. This allows for a methodical and sequential progression through both the animations and informative texts, with each change being triggered by the user's interaction with the button. This upholds DP1 in allowing dynamic animations whilst retaining the ideals of DP2 in allowing users to move through the consensus mechanism at their own speed. The idea behind the Educational page is to allow for a chronological process in creating the next block in the network, depending upon the block the user selected. For instance, if the user selected block 27 as Figure 2 displays, the educational tool will pull authentic data from the network in order to show the user the step-by-step process of constructing block 28 and adding it to the ledger.

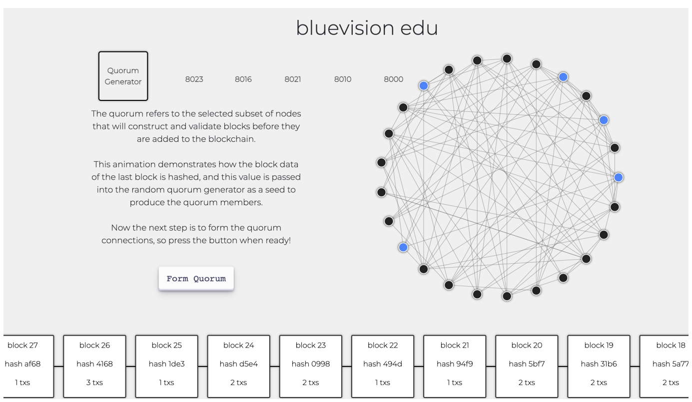

Figure 3: Derive Quorum design page

Derive quorum design. Upon the user pressing the Derive Quorum button shown in Figure 2, a smooth animation will play that shows block data from the selected block being passed into a "Quorum Generator", which is representative of the quorum generation algorithm, that outputs the quorum members from the selected state in the network. After the animation displays the quorum members, the nodes in the network graph will be colored blue in congruence with the coloring method from the live network. The informative text explains to users that the quorum refers to the selected subset of nodes that will construct and validate blocks in order to add blocks to the ledger. The text also goes on to explain that the animation demonstrates how block data of the last block is hashed and passed into this generation algorithm as a seed in order to randomly produce the quorum members in constructing the next block. In concluding the informative text the user is then encouraged to press the Form Quorum button, in order to begin the next step in the process.

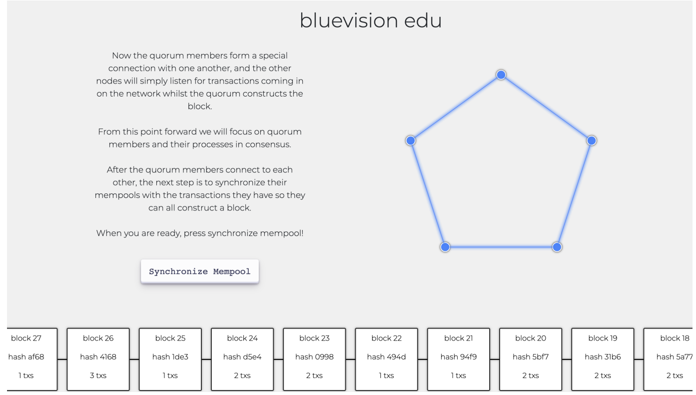

Figure 4: Form Quorum design

Form quorum design. In prompting the Form Quorum button, the animation will slowly fade out all non-quorum members, in order to keep the animations clear and focused upon the quorum members. The quorum members will then reposition themselves based on the geometry of a polygon corresponding to their number. For instance, if there are five quorum members, they will align in a pentagonal formation, while six members will form a hexagonal arrangement. This retains the feelings of a decentralized, distributed network, even if the animation is focusing on a subset of nodes. The animation will then show the quorum members sending a blue "light" to each other to represent a connection, asynchronous with the Form Quorum message in the Live Network graph. The informative text details the fact that the quorum members will form this special connection amongst one another, and also explains the purpose of fading away the rest of the non-quorum nodes, as the non-quorum nodes will simply listen for incoming transactions from light nodes while the quorum members come to consensus on the next block in the ledger. After, the text encourages the user to progress to the next step in consensus, the Synchronize Mempool phase.

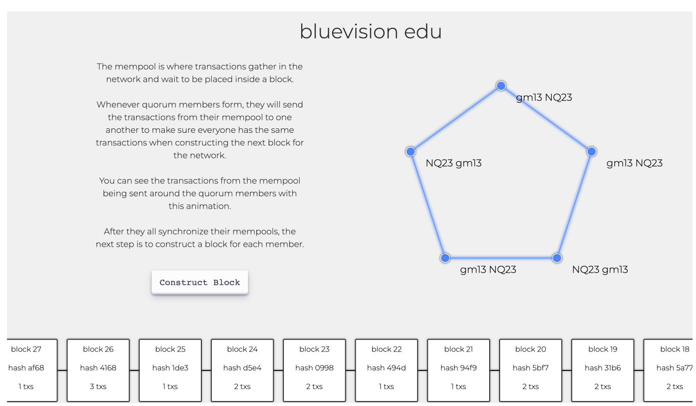

Figure 5: Synchronize Mempool design

Synchronize Mempool design. When initiating the Synchronize Mempool phase, the visualization will pull the transactions that were inside of the network at the selected block. The animation will then sequentially send the transactions' hashes to each quorum node, indicating the synchronization of the mempool that each quorum node undergoes at this step in the consensus process. While the transactions are sent around in the animation, the text will update educating the user in the fact that the mempool is where transactions gather in the network's nodes in waiting to be placed into a block. The text then goes on to explain the aforementioned animation, elaborating on the necessity for congruent mempools between quorum nodes for the fact of constructing equal blocks. After the mempool is synchronized, the text instructs the user to activate the Construct Block button, driving forward the next step in the consensus process.

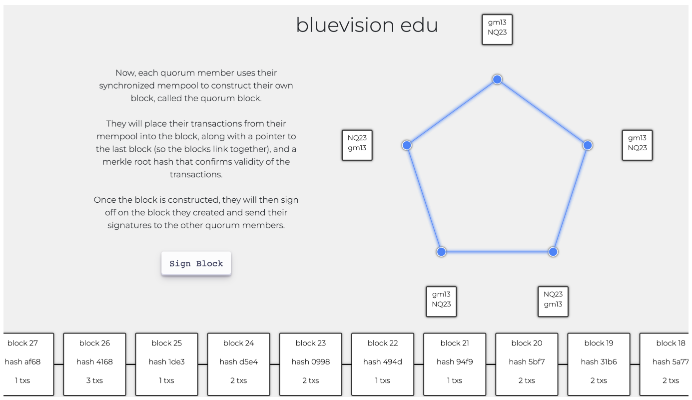

Figure 6: Construct Block page design

Construct Block design. The Construct Block animation will take each of the quorum nodes' mempools and place them inside of a constructed block, displaying the functionality in which each quorum member constructs a block with their given mempool. Information displayed explains that the quorum nodes used their now updated mempools in order to construct the block, denoted as the quorum block. Also brought to light is the entire content of the block, namely the transactions, merkle root hash, and the pointer to the previous block that is placed inside of a block upon construction. After these details are revealed, the text then prompts the user to initiate the next step, Sign Block.

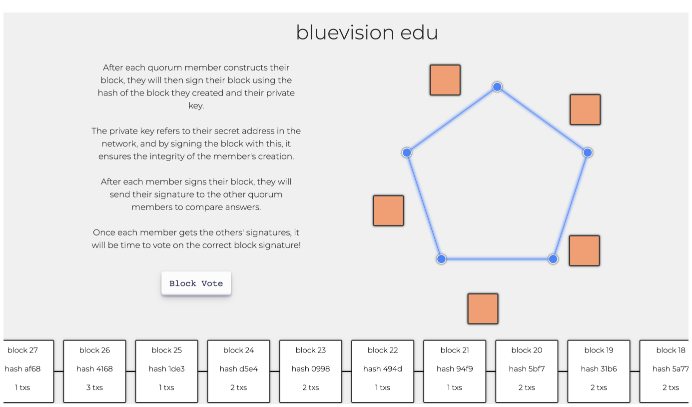

Figure 7: Sign Block design

Sign Block design. The Sign Block animation boasts an impressive animation in which each quorum member "signs" their block with an orange color, in equivalency to the Sign Block message color from the Live Network view. The text explains that this signature actually comes from the hash of the block they created and their own private key, but the colored animation assists in making the animation tactful for NUsers. The text also goes on to explain that the private key represents the nodes' secret addresses in the network that only they can access, ensuring integrity and validity in quorum block construction. Finally, the text goes on to explain the process that is occurring in the animation, by which the now signed blocks are being sent to each of the other nodes' positions, indicative of the transmissions of block signatures that occurs within this step in the consensus protocol. After the blocks are sent between members, the following phase is to vote on the correct block.

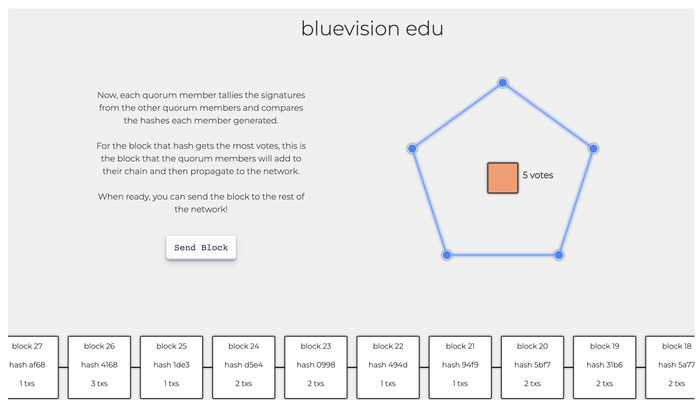

Figure 8: Block Vote design

Block Vote design. The Block Vote animation displays a smooth amalgamation of the blocks that are being transported around the quorum nodes into one block in the midst of the nodes. This block is then voted upon by the quorum members, displaying the number of votes for this block to be added to the network. The text explains the process in tallying block votes between quorum members, namely the democratic vote on the hash of the most popular block. In proceeding the text tells the user to progress in the next step by sending the block to the rest of the network.

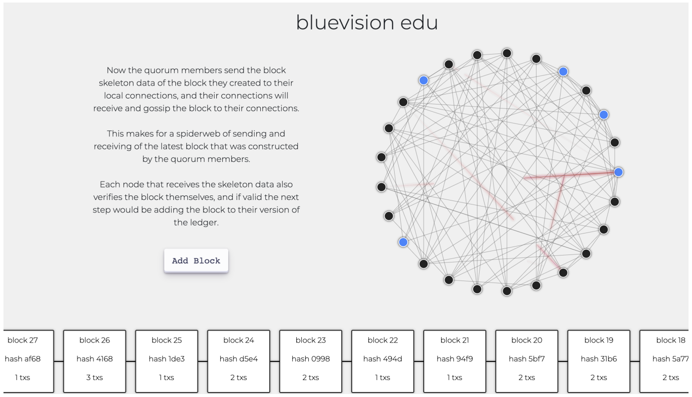

Figure 9: Send Block design

Send block design. In animating the Send Block process, the rest of the nodes and network are brought back to the life on the screen. The block is then sent as a red ”light” between the nodes in the network, exactly how the message is displayed for this step in the Live Network page. The user is informed that the quorum members now send the data of the block they created to the rest of the network, and the data is gossiped across the entirety of nodes. Once every node has received and verified the newly constructed block, the next step is to add the block to the ledger.

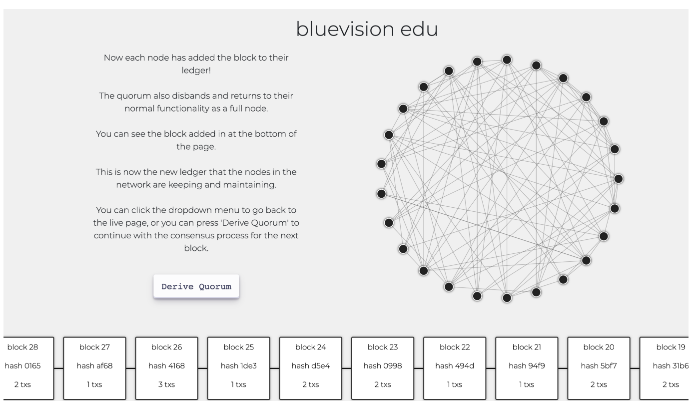

Figure 10: Add Block design

Add block design. Once the user presses Add Block on their front end, the ”newly” constructed authentic block from the network is added to the ledger at the bottom of their screen. This animation has now completed the process of constructing the chronological block and adding it to the ledger. The quorum also disbands by turning back to congruently colored nodes. After this step, the consensus process is completed for the user’s initial selected block. However in the visualization, there is a seamless transition mechanism that enhances user experience and engagement. For instance, if a user chooses block 27, by the time they reach the Add Block phase, block 28 is added. What truly sets the visualization apart is its fluid continuity; upon completing the consensus process for one block, the system is instantly primed and ready to transition on the next block, in this case block 29, without any need for the user to exit or refresh the page. This continuous loop not only showcases the dynamic nature of our visualization but also ensures an uninterrupted, immersive experience for the user. The user can also exit this loop at any given time, returning to the live view of the BlueChain network, also promoting configurability and accessibility in totality of the visual tool.

V. User Study

To assess the utility and effectiveness of BlueVision, a user study was carried out involving a select group of participants. These individuals were provided guidance on utilizing the tool and were asked to respond to a series of objective and subjective questions. The subsequent subsections cover the experimental methodology employed and provide a comprehensive analysis of the obtained results.

A. Implementation and Setup

The participants for this research were divided into two distinct groups based on their prior familiarity with blockchain technology: NUsers and EUsers. The NUsers consisted of 10 computer science students (ages 19-30) participating in the Cloud Computing REU program at Boise State University (BSU), that possessed minimal to no prior knowledge of blockchain technology. Conversely, the EUsers (ages 19-24) were comprised of individuals from the Blockchain Technology REU program at BSU, possessing a comprehensive understanding of blockchain technology.

The experimental setup consisted of an HP Z2 Tower G5 Workstation accompanied by two 23-inch screens, each with a resolution of 1920 x 1080. BlueVision was preloaded in a browser on one screen, enabling participants to commence their navigation. To complete the objective and subjective questionnaires, participants utilized the second screen to access Google Forms.

B. Experimental Procedure

The study was performed on July 26, 2023, collecting data from two participants at a time. The following is the procedure followed for each participant.

Introduction. To begin the study, a participant is introduced to the purpose of the study and are given a brief explanation on how to navigate BlueVision. Following this introduction they are free to explore and utilize the tool according to their own preferences and pace.

Questionnaires. The participant begins by completing three demographic questions (age, undergraduate major, and REU program) and a Pre-Evaluation Survey. This survey collects data on their current knowledge in blockchain - answers are collected using an ordinal scale from 1 (least knowledge) to 5 (most knowledge). Upon completion of this survey, the participant begins by configuring the network to their preferences from the configuration page. Following the launch of the live network, the participants begins interacting with the live network component and is given simple instruction on how to begin the educational component when ready. After the participant feels they have spent adequate time browsing BlueVision's live network page and educational page, they are asked to close the tool and begin answering the questionnaires. The objective questionnaire consists of 15 questions that can be categorized into 2 abstracts: consensus protocol step and information type. There are 8 consensus steps that coincide with the various stages of the educational tool. The information types tested are conceptual questions relating to basic knowledge of blockchain. The participant then completes a Post-Evaluation Survey, which collects data on their knowledge in blockchain after using the Educational tool. The questions are the same as those in the Pre-Evaluation Survey and are collected using the same oridnal scale. Lastly, the participant completes a subjective questionnaire consisting of 11 questions. These questions are used to measure the user's overall feelings towards BlueVision; including contentment, informativeness, usability, efficacy, and design choices.

C. *Analysis of Results*

Responses from the various questionnaires were collected and analyzed in the following manner. First, the average rating on the Pre- and Post-Evalutation surveys was calculated for both user groups. This is shown in Table II. Second, the average accuracy for each user group was calculated and compared in respect to each educational page and question type. This is shown in Table III and Table IV. Third, the average rating was calculated from NUsers and EUsers on the subjective questions. This is shown in Figure 11.

(1) Analysis of Pre- and Post-Evaluation Surveys.

The NUsers group exhibited the most significant improvement in their comprehension of general blockchain technology topics and consensus protocols. As shown in Table II, their self-reported knowledge increased by an average of 0.7 for blockchain technology and 0.8 for consensus protocols, rated on a scale from 1 to 5. On the other hand, the EUsers group demonstrated the most substantial knowledge enhancement in general distributed networks, with closely matched improvements in general blockchain technology topics and consensus protocols. This suggests that BlueVision Educational effectively achieved its objective of educating users about consensus protocols and network activity. However, it is worth noting that both user groups did not exhibit significant improvement in their understanding of nodes in a network. Therefore, in future iterations of BlueVision, this aspect should be more comprehensively addressed and discussed to ensure a well-rounded and thorough educational experience for users.

The findings from this research indicate that BlueVision Educational successfully enhanced users' knowledge in specific areas, particularly in blockchain technology and consensus protocols. Nonetheless, the study also highlights the importance of continually refining and expanding the educational content to ensure comprehensive coverage of all essential concepts related to blockchain networks and their underlying mechanisms.

(2) Analysis of Objective Questionnaire.

As anticipated, the EUsers group outperformed the NUsers group in the research study. However, an analysis of the objective question responses, as depicted in Table III, revealed several challenging questions that both user groups struggled with.

User Group	BT	DN	CP	NN	CS
NUsers PRE	2.10	2.00	1.80	2.60	3.50
NUsers POST	2.80	2.60	2.60	3.20	3.20
EUsers PRE	4.14	3.57	4.00	4.57	4.29
EUsers POST	4.71	4.29	4.57	4.57	4.43

Table II: Compares average rating of knowledge, using a scale from 1 to 5, of the following topics before and after using BlueVision: blockchain technology (BT), distributed networks (DN), consensus protocls (CP), nodes in a network (NN), and computer science (CS). PRE indicates the ratings from the Pre-Evaulation survey and POST indicates the ratings from the Post-Evaluation survey.

Q15 assessed the participants' ability to match each step of the quorum consensus process in BlueChain in the correct order. Only 36% of NUsers and 48% of EUsers provided accurate answers to this question. Many users managed to correctly match the initial 2-4 steps but faced difficulties in accurately arranging the subsequent steps after a mistake. Since understanding consensus is a key focus of BlueVision, this research aims to enhance the clarity and distinction of each step to benefit future users.

Q12 required users to identify what nodes do upon receiving a new block. The correct response was both to validate the block and send it to the node's neighbors. The results indicated that 30% of NUsers and 57% of EUsers answered this question correctly. However, a majority of users chose at least one of these correct actions, but they failed to select both, leading to an incomplete answer. Similarly, in Q9, users were asked to recall how quorum members sign their block, with the correct choices being to use the hash of the block and their private key. Only 30% of NUsers and 29% of EUsers answered this question correctly, with most users selecting only one of the correct choices.

Q13 demonstrated the most significant gap in accuracy between the user groups, with NUsers having a 20% accuracy rate and EUsers achieving 100% accuracy. This question inquired about what happens to the quorum after a block is added, suggesting that this particular information was not effectively conveyed in the tool. EUsers' superior performance on this question could be attributed to their prior knowledge of blockchain.

The remaining questions displayed relatively high accuracy percentages for both EUsers and NUsers. These results highlight the topics that require clearer explanations within BlueVision Educational. It is important to note that participants spent no more than 10 minutes exploring BlueVision before attempting the objective questions. Since most questions were multiple-choice with intricate answer choices, users may not have thoroughly studied and prepared for them in advance. Given the opportunity to use the tool while answering the questions, the overall accuracy shown in Table IV would significantly improve, as many of the questions are directly addressed in BlueVision Educational. This further emphasizes the importance of allowing users more time and hands-on experience with the educational tool to enhance their understanding and performance in answering objective questions.

Question	Educational Page	Question Type	Accuracy	
			NUsers	EUsers
Q1	Derive Quorum	MC	0.5	1.00
Q2		MC	0.9	0.86
Q3	Form Quorum	MC	0.4	0.86
Q4		TF	0.7	1.00
Q5	Synchronize Mempool	MC	0.6	1.00
Q6		TF	0.6	0.86
Q7	Construct Block	MC	0.6	0.86
Q8		SAA	0.35	0.64
Q9	Sign Block	MC	0.3	0.29
Q10		TF	0.8	0.71
Q11	Block Vote	TF	0.9	1.00
Q12	Send Block	MC	0.3	0.57
Q13		MC	0.2	1.00
Q14	Add Block	MC	0.4	1.00
Q15		M	0.36	0.48

Table III: Results of average accuracy on each objective question for both NUsers and EUsers. The questions are categorized by both educational page and question type. The eight educational pages correspond to a page in the BlueVision Educational tool. The question types are as follows: multiple choice (MC), true or false (TF), select all that apply (SAA), and matching (M).

User Group	Accuracy
NUsers	52.73
EUsers	80.87

Table IV: The average accuracy for NUsers and EUsers for the Objective Questionnaire.

(3) Analysis of Subjective Questionnaire.

Figure 11 illustrates the users' overall sentiments regarding their experience with BlueVision and its design. The majority of users either agreed or strongly agreed with several positive aspects of BlueVision. They found the tool to be user-friendly, concise, easy to use, and it encouraged them to continue exploring blockchain networks. Additionally, most users expressed satisfaction with BlueVision's effectiveness in teaching them about the blockchain consensus process and network activity. However, two users disagreed that BlueVision effectively served as a tool for educating users about these topics. Similarly, only two users reported being dissatisfied with their understanding of the consensus process and network activity after using BlueVision.

Q9, which inquired about the informativeness of BlueVision, garnered the most disagreement. Specifically, it asked whether the tool provided sufficient information to answer the objective questionnaire. The negative feedback indicates the need for improvement in the information provided within BlueVision, ensuring that it is more comprehensible and readily accessible.

Taking these results into account, future research may aim to implement necessary adjustments to BlueVision to refine the educational content and presentation. By enhancing the clarity and accessibility of information, an optimal learning environment is created for users, enabling them to gain a deeper understanding of blockchain consensus processes and network activity through the utilization of BlueVision.

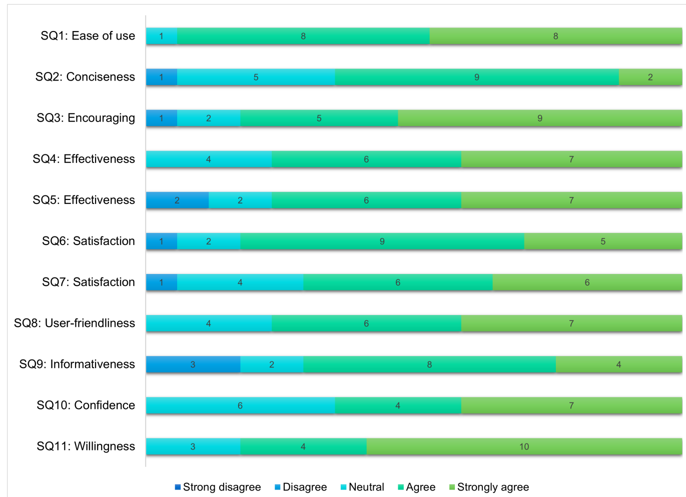

Figure 11: Subjective Survey

VI. Conclusions and Future Work

This sections discusses the future work within blockchain visualization and concludes findings from this research.

A. Future Work

BlueVision was developed using a combination of HTML, CSS, JavaScript, Node.js, D3.js, Java, and anime.js. These languages and frameworks are generally compatible with most devices currently available. However, it's important to note that the initial development was undertaken using a high-performance HP Z2 Tower G5 Workstation, enabling efficient handling of complex animations. On devices with lower computational capabilities, the animation performance tends to be less smooth and efficient. Moreover, the design and layout of BlueVision pages have been optimized for a minimum 23-inch monitor display, as this was the primary development environment. The research did not extensively test BlueVision's performance on various device sizes. Moving forward, a key research objective is to refine the BlueVision codebase, optimizing the animations and HTML to ensure seamless functionality across a broader range of devices.

An additional facet of BlueVision that demands attention is its requirement for users to download both BlueVision and BlueChain's code bases to their device for usage and accessibility. This necessity introduces a significant barrier for NUsers, who may not be accustomed to interfacing with the intricacies of code base manipulation and software installation. In accordance with the design principles, such a tool should be universally accessible and not require technical expertise to engage with. In the interest of user-friendliness, particularly for those new to the blockchain domain, future work aims to host BlueVision as a fully online platform. This move would eliminate the need for users to download and install any repositories on their device, thereby simplifying the user experience drastically. For EUsers, this modification could also promote a more robust and convenient experience, with instances of BlueVision becoming readily accessible from any device without the need for specific software setup. In essence, the objective is to democratize access to BlueVision, making the wealth of information and insight it provides accessible to a broader audience.

Finally, BlueVision's current visualizations of BlueChain data are rooted in the assumption that all nodes within the BlueChain network operate with honesty and efficiency. This can inadvertently present a somewhat idealized image of blockchain operations, which does not account for scenarios involving malicious, uncooperative, and/or inefficient nodes. Expanding the visualization capacity to depict anomalies, such as dishonest behavior or inefficient operations, could enhance the tool's educational capabilities. By integrating visualizations that represent various network conditions, including thesse faulty conditions or use cases beyond DeFi, BlueVision could more comprehensively educate users about the diverse, complex scenarios that can arise in a blockchain network. Thus, moving forward, broadening the scope of BlueVision to incorporate these aspects will be an important focus.

B. Conclusion

This study presents an online visualization tool, BlueVision, for exploring blockchain data and learning about blockchain processes. BlueVision features a plethora of animations, interactions, and dynamic visualizations that convey information regarding distributed ledger technology in an educational manner. These features cater to needs of NUsers when utilizing blockchain data visualizations, namely, the necessity to educate and guide them on the intracies of blockchain technology. The same features also provide satisfaction in EUsers requirements for advanced data reagarding the network and also prove to be educational in less known topics regarding consensus mechanisms and network activity. This study aspires to promote the further development in blockchain data visualization and research, placing an emphasis on enhancing public understanding of blockchain technology.

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