WIP: CryptoQuest - Interactive Animation Series for Teaching Cryptography, Post-quantum Cryptography, and Cybersecurity Using Extended Reality (XR)

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Abstract*—This research-to-practice WIP paper explores the application of interactive animation and extended reality (XR) in computer-based instruction, specifically in the areas of cryptography, post-quantum cryptography, and cybersecurity. Interactive animations, characterized by their dynamic, visually stimulating, and participatory nature, offer a promising avenue to transform traditional didactic teaching approaches into an immersive learning environment. This method leverages the dual-coding theory, suggesting that information processed through visual and auditory channels is more readily retained. Additionally, by integrating interactive elements such as problem-solving tasks and immediate feedback mechanisms within the animations, this approach caters to diverse learning preferences and needs, thereby fostering a deeper understanding of complex theoretical concepts. Our project aims to develop a series of interactive animations tailored for high school and university students. The integration of XR technology enables students to tangibly interact with virtual cryptographic systems or algorithms, solve puzzles, navigate through virtual mazes, and complete various quests correlated with the lesson concept. Additionally, XR elements can be superimposed onto physical environments, thus creating an augmented reality scavenger hunt or an interactive storytelling experience that promotes active participation. The project builds upon our previously implemented cyberinfrastructure (CyEd), ensuring robust and scalable delivery of educational content. vizLab is a tool we developed within CyEd to allow students with little programming experience to engage in interactive programming exercises. The integration with vizLab promotes the practical implementation of algorithmic concepts learned through the animation series. We conducted a survey that evaluated the project from different angles, with the preliminary findings indicating a positive student perception, increased engagement, and enhanced interaction with the learning environment. In summary, this research-to-practice approach demonstrates the transformative potential of interactive animations with extended reality (XR) in computer-based instruction. The implications of this research-to-practice offer insights and methodologies that can be adapted and applied across various disciplines and academic levels.

***Keywords*—Computer-based instruction, Virtual reality, Cognitive theories, Constructivist, Research to practice**

I. Introduction

A. Overview

In this paper, We explore the practical applications of interactive animations and extended reality (XR) in computer-based learning. Our focus is on cryptography, post-quantum cryptography, and cybersecurity. CryptoQuest presents a promising avenue for revolutionizing traditional teaching methods, making learning more immersive. Rooted in the dual-coding theory, which suggests that information conveyed visually and audibly is better retained, this approach integrates interactive elements like simulations, problem-solving tasks, and instant feedback mechanisms within animations and extended reality. Doing so accommodates diverse learning styles, facilitating a more profound comprehension of complex theoretical concepts. Our initiative revolves around crafting a series of interactive animations tailored for both high school and university students. These animations are crafted to captivate students' attention while adapting to their individual learning speeds and proficiency levels, ensuring personalized educational experiences. Augmenting this endeavor with XR technology takes it further, allowing students to interact with virtual cryptographic systems and algorithms, solve puzzles, explore virtual mazes, and engage in quests aligned with the lesson's core concepts. XR elements can seamlessly blend into physical surroundings, offering experiences like augmented reality scavenger hunts or interactive storytelling sessions, fostering active involvement and bridging the gap between abstract theories and real-world applications.

B. Contributions

The intellectual merit of this research-to-practice lies in its potential to redefine educational practices in the engineering and computing fields. The study advocates that learning is most effective when students actively construct their knowledge base through engaging, context-rich experiences that do not overwhelm their cognitive processing capacities.

- CryptoQuest uses various technologies and educational theories to improve student engagement, motivation, and knowledge retention. It provides a multi-modal medium for students to interact with the learning material and understand complex concepts more easily.
- We are integrating CryptoQuest with our existing cyber-infrastructure, CyEd [1]. Specifically, we are using the vizLab tool [2], which is designed to provide interactive programming exercises for students with little to no programming experience. The integration of vizLab with our animations emphasizes the practical application of algorithmic concepts covered in the series.
- We conducted a comprehensive survey to evaluate the CryptoQuest series and the hosting system from various perspectives, including engagement, learning effectiveness, usability, and conceptual understanding.

C. CryptoQuest Story

The story takes place on planet Helix, where technology has completely overtaken society. Some hostile forces intend to infiltrate Helix's inner workings and crash the server that keeps the society running. These forces have captured the scientist who holds the key to stopping them. His two children, Gina and Gino, are the only ones capable of decrypting the clues their father left behind with the help of their father's robot, Crypto. The students watching the episodes are part of the story, and they can help the main characters solve the mysteries by decrypting or encrypting messages and searching for hidden clues that can help find the missing scientist.

II. Related Works

Numerous studies have highlighted the positive impact of gamification and game-based learning on student motivation, learning outcomes, and academic achievements [3], [4]. Both are widely recognized as effective approaches for fostering engaging learning environments across all educational levels, from kindergarten to elementary school [5]. Gamification and game-based learning can be used in various disciplines, such as computer science, mathematics, astronomy, physics, medicine, and law, demonstrating its versatility in education [6]. In one study [7], researchers incorporated game design elements like experience points, levels, leaderboards, challenges, and badges, and the findings underscored increased student engagement and active involvement in course activities. Similarly, another investigation [8] implemented gamification within a web-based learning system dubbed "Classroom Live," targeting undergraduate students. By integrating elements like experience points, levels, and in-game rewards, researchers observed enhanced student enjoyment and participation in class activities. Furthermore, video explanations have also been proven to help students better comprehend complex concepts compared to traditional methods [9] and increase their motivation to learn [10]. Finally, existing research [11] has shown that XR in education can support engagement, motivation, and self-efficacy.

We aim to contribute to this body of work by utilizing a novel multi-modal approach that integrates gamification, video animations, and extended reality within the same learning environment.

III. Theoretical Framework

Our research is based on two theories - constructivist and dual coding theories, as shown in Fig. 1. These theories combined suggest that meaningful learning can take place when two key factors are present: (i) students are actively involved in constructing their knowledge by participating in engaging experiences and by searching for and solving clues in the story, and (ii) rich content is provided in both verbal and visual forms. Learning is optimized when both verbal and visual representations are used, as they do not overload a single channel and can reinforce each other without overwhelming the students' cognitive abilities. [12], [13].

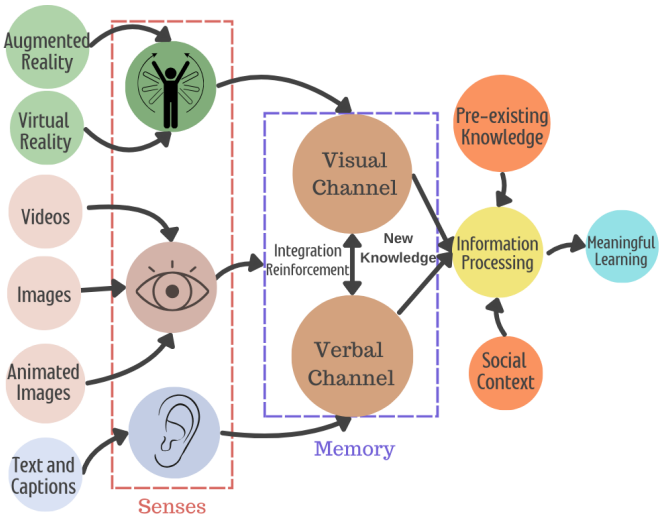

Fig. 1. Overview of the study's theoretical framework that combines the constructivist and dual coding theories.

IV. Research Methodology

Our research questions provide a clear direction for our methodology and help define its purpose and scope. This study aims to answer the following research questions.

RQ1 How engaged are students with the CryptoQuest series? This question aims to measure participants' interest and involvement in the series and determine which elements contribute most to keeping them engaged.

RQ2 How effectively is the CryptoQuest series improving students' understanding of selected cryptography and

cybersecurity concepts? This question assesses the educational impact of the series, focusing on how well students grasp selected topics after engagement.

RQ3 How user-friendly is the CryptoQuest platform? This question explores the ease of navigation, clarity of instructions, and overall user interface design, which are crucial for a positive student experience.

To answer these questions, ten students watched the interactive CryptoQuest videos and used the system. They were given a survey promptly after participating in these videos, which took approximately 30 minutes to complete. The survey consisted of both Likert scale and free-response questions, which were compiled for analysis. The Likert scale questions were analyzed quantitatively, while the free-response questions were analyzed qualitatively to identify the main themes.

V. System Design and Components

The CryptoQuest system's design consists of various components and services that aim to provide a seamless and engaging user experience within a web-based application framework, see Fig. 2. CryptoQuest provides a multi-modal interactive learning environment for students. Students can switch from watching episode videos to an online virtual reality space where they can search for clues or pieces of evidence. Fig. 2 shows an example virtual room created on the CryptoQuest platform, representing the missing dad's office. Students can search for hidden encrypted messages. Once found, students must decrypt the message and provide the correct answer to proceed with the next episode. Additionally, CryptoQuest provides another mode of interactivity where students can interact with some of the story's main characters or use cryptographic tools in augmented reality, see Fig. 4

A. Responsive Web Interface

The responsive web interface is designed to adapt seamlessly to various screen sizes and devices, ensuring optimal user experience across desktops, laptops, tablets, and smartphones. The interface provides a visually appealing and intuitive environment for students to navigate the CryptoQuest platform. Once users create an account and log into the system, they can select one of the available episodes to watch. Each episode consists of smaller sub-sections with one or more associated videos to watch and quizzes to test and reinforce their knowledge. Fig. 3 shows a video of a conversation between the two main characters in the series, Gina and Crypto.

B. vizLab Environment

We are integrating the CryptoQuest system with our CyEd platform, specifically with the vizLab tool. This integration allows students to design cryptography algorithms using a block-based language, which is automatically translated into Python for online execution, see Fig. 5. Students can share the algorithms they create with their classmates and teachers, which promotes a collaborative learning environment. Moreover, students can use the constructed code to encrypt or decrypt messages featured in the episodes, making it easier to handle longer and more complex messages.

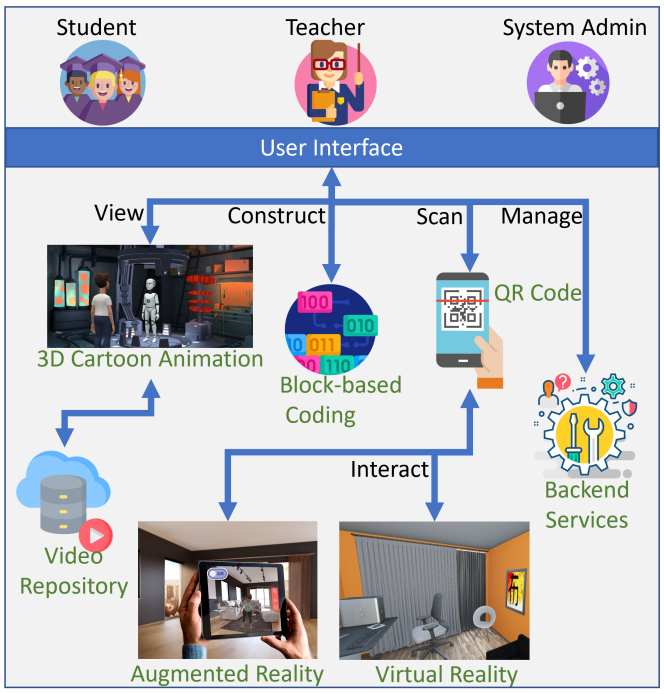

Fig. 2. CryptoQuest system main functionalities and components.

Fig. 3. Screenshot depicting a conversation between two main characters in the series, Gina and Crypto.

C. Database Management

The database serves as the backbone of the CryptoQuest system, storing essential data related to students, teachers, episodes, quizzes, animation videos, and other relevant information.

D. User Management and Authentication

User management functionalities manage user accounts, profiles, and permissions within the CryptoQuest system. These include user registration, profile customization, password management, and account activation/deactivation. User authentication mechanisms are implemented to secure access to the CryptoQuest platform, protecting students' and teachers' accounts and sensitive information. Three types of users use the system: teacher, student, and administrator.

Fig. 4. Augmented reality experience features a student interacting with one of the story characters. The character with some network devices is superimposed onto a physical environment inside a university classroom.

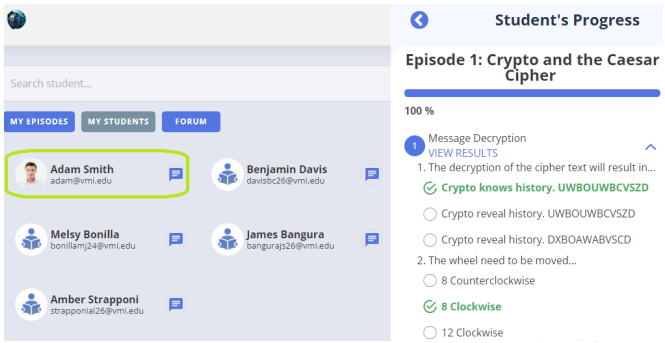

Fig. 6. Teachers can view all student profiles and track their progress. CryptoQuest system can show the performance and progress at question and quiz levels.

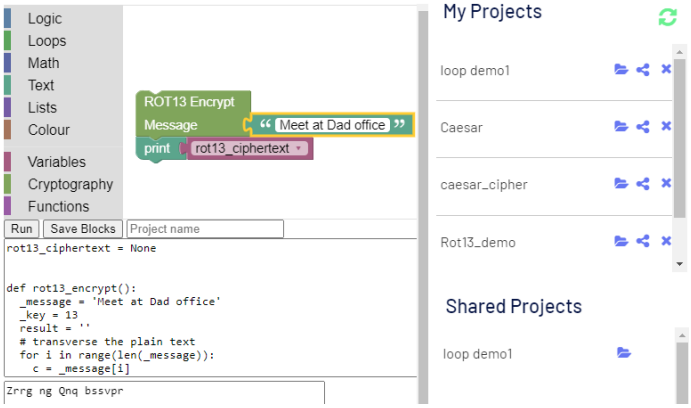

Fig. 5. Students can create block-based algorithms that will be directly translated into Python code. Generated codes can be used to encrypt or decrypt secret messages embedded within the episodes.

E. Quiz Management

Quiz management capabilities facilitate creating, customizing, and administering quizzes and assessments within CryptoQuest courses. Teachers can design quizzes with diverse question types, set grading criteria, and monitor user/student performance. At the same time, learners can engage in interactive quizzes to reinforce their understanding and track their progress throughout the learning journey. Fig. 6 shows how teachers can track students' progress.

F. Episode Management

Episode management functionalities empower administrators to create, organize, and manage the episodes. This service includes curriculum planning, content creation, instructor assignment, and monitoring of course progress and completion rates. The CryptoQuest series covers topics related to classical encryption, symmetric encryption, public-key encryption, quantum computing, and post-quantum cryptography.

VI. Initial Results and Discussions

This section examines the initial results from the CryptoQuest survey. The survey questions, shown in Table I, examine the CryptoQuest series from different angles, including student engagement, educational value, usability, and ease of use. The participants provided both quantitative and qualitative feedback. They were purposefully sampled from a pool of undergraduate computer science sophomores who are enrolled in the "Internet and Mobile Programming Course" and have prior experience or an interest in learning cybersecurity or cryptography.

A. Quantitative Analysis

Students rated the engagement of the CryptoQuest episodes between 3 and 4, with a mean of 3.8, indicating a relatively high level of engagement. Results show that the series effectively explained and communicated the selected topics, with a mean score of 4.2. The user interface received mixed reviews with scores from 2 to 5, averaging 3.7, indicating a generally positive but varied experience. Additionally, results suggest a significant improvement in conceptual understanding for most students, while others saw little, with an average score of 3.8. Conceptual understanding ratings may reflect the first-time experience and might change after using CryptoQuest frequently. The average score for the effectiveness of visual aids was 4.3. This indicates that the visual aids were generally helpful in aiding understanding.

B. Qualitative Analysis

The qualitative analysis focused on what students valued most and pinpointed areas for improvement. The revealed insights are essential for refining and enhancing the series' educational impact. Three main themes emerged during this part of the analysis.

1) Positive Feedback: Students appreciated the creativity, storyline, interactive elements, and integration of educational content into the game format. Selected excerpts from the students' responses when asked what they like most about the series:

- *"I liked the videos; they were neat."*
- *"The videos being short and engaging."*
- *"It had captions and good animation and was easy to follow."*
- *"It was easy to digest."*
- *"Puzzles that are directly related to the content."*

2) Critiques: Areas for improvement included animation and voice quality. Switching between videos and quizzes was challenging for some students. Selected excerpts from the students' responses when asked what they like least about the series:

- *"I didn't like how I'd have to switch between the videos and the quiz."*
- *"Sometimes the voices felt a little off."*
- *"A little difficult to do cipher the first time."*

3) Technical Issues and Responsiveness: Most students found the platform responsive and did not encounter technical issues, although a few noted minor problems related to usability and voice quality.

4) Future Topics: Suggestions for future episodes included more diverse cryptography topics and basics of programming. One student suggested the need for a flashcard-type system to help retain knowledge. Another student suggested using a reward system.

TABLE I
SELECTED QUANTITATIVE QUESTIONS FROM THE SURVEY

Category	Question	Type	Avg. Score	Std. Dev.
Engagement and Experience	How engaging did you find the episode(s) you watched? ? (1 being not engaging at all, 5 being very engaging)	Likert Scale 1 to 5	3.80	0.40
Learning and Effectiveness	How well do you feel the CryptoQuest series explained the selected concept/topic of cryptography and cybersecurity? (1 being not well at all, 5 being very well)	Likert Scale 1 to 5	4.20	0.60
Usability and Ease of Use	How would you rate the overall user interface and design of the CryptoQuest series platform? (1 being very difficult to use, 5 being very easy to use)	Likert Scale 1 to 5	3.70	0.9
Usability and Ease of Use	Was it easy to navigate between different episodes and resources on the platform?	Multiple Choices	Yes: 8 No: 0 Somewhat: 2	
Usability and Ease of Use	Did you encounter any technical issues while using the platform?	Multiple Choices	Yes: 1 No: 6 Somewhat: 3	
Usability and Ease of Use	How responsive was the platform on your device (e.g., computer, tablet, smartphone)?	Multiple Choices	Vey responsive: 7 Not responsive: 1 Somewhat: 2	
Conceptual Understanding	How much do you feel your understanding of the selected topic has improved after watching the series? (1 being no improvement, 5 being significant improvement) (Rating scale)	Likert Scale 1 to 5	3.80	1.17
Conceptual Understanding	How effective were the visual aids in helping you understand the content?	Likert Scale 1 to 5	Vey effective: 8 Not effective: 1 Somewhat: 1	

VII. CONCLUSIONS AND FUTURE WORK

This research work showcases the use of interactive animations and XR in computer-based instruction. By seamlessly integrating theory with practical implementation, the project establishes a novel model for teaching Cryptography, Post-quantum Cryptography, and Cybersecurity, ensuring accessibility, engagement, and efficacy. The findings of this research-to-practice endeavor reveal a high level of student engagement and conceptual understanding. In the future, we plan to continue developing and revising CryptoQuest based on students' feedback, emphasizing more topics in post-quantum cryptography.

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