Converting Physical Textbooks into Interactive and Immersive 'Phygital' Textbooks: A Proposed System Architecture Design for Textbook Companion Apps

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Abstract

In this research, a system architecture design framework is proposed which can be standardized for textbook companion apps, and is customizable for any subject, especially pedagogically complex subjects like Biosciences. The architecture uses the images in the textbook itself as a marker for generating Augmented Reality based interactive content. Apart from standard interactive affordances, Augmented Reality based in-screen interactions and Generative Pre-trained Transformers (GPT) enabled on demand 'Ask me anything' feature was introduced in the app design. Eleven participants validated the usabiliy of the proposed model using SUS (system usability score) on three complex Biology topics for the high school level. The proposed app design had a higher usability score when compared to the standard textbook app. Overall, the proposed system architecture design has the potential to improve the usability of any textbook companion app and consequently the learning experience.

Keywords

textbook companion apps, system architecture design, mobile learning, phygital textbook design

1. Introduction

Textbook companion apps are a type of mobile app that is designed to complement a traditional physical textbook [1]. These apps typically provide additional features and functionality that are not available in the textbook itself such as interactive quizzes, AR/3D models and animations, audio narration, and external links to additional resources. This combination of a physical textbook augmented by an supplementary digital interactive interface is termed as a 'Phygital' textbook [2],[3]. Textbook companion apps are often considered as the standard digital part of a 'phygital textbook'. There are a number of ways that textbook companion apps can be used to enhance the learning experience, specifically for STEM subjects like Biology [4],[5], or Chemistry, where the app can provide students with interactive exercises and quizzes to help them learn about the different parts of a cell, or could provide students with 3D models of molecules to help them visualize chemical reactions. In social science subjects, a textbook companion app could provide students with audio and video recordings of historical events to help them understand them more deeply. By providing additional information and interactivity,

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textbook companion apps can help students to learn more effectively, stay organized, improve their grades, and engage with the learning content more deeply fostering immersive learning. [6].

1.1. Contribution of this research

The following is the key contribution of this research: — Development of a novel system architecture design framework for mobile companion apps, which is customizable and does not require any additional hardware, except for a standard Android OS-enabled mobile phone.

2. Literature Review

2.1. General concerns regarding educational app frameworks

Many evaluation frameworks for educational apps [7], [8],[9] have been proposed in order to simplify and facilitate the app development evaluation process. However, some of these frameworks emphasize on the technical aspects of the apps rather than the educational aspects, as stated in the comprehensive work by [10]. Furthermore, many of these frameworks are subject-specific, and therefore are inapplicable to other subject-based apps. For example, frameworks for language learning apps (e.g. Duolingo [11]) cannot be applicable for STEM subject apps, even if they use gamification as a core model. However, some of these studies indicate that there are purely educational features (e.g. tools supporting active reading interactions) that can be used to identify high-quality educational apps. In this proposed research, such educational features are identified and aggregated as a set of immersive learning enabling affordances and interactions, which are transferable and can be generalized across domains.

2.2. Challenges with Augmented Reality based Educational App frameworks

The work by [12] analyzed existing Augmented Reality (AR) app frameworks, focusing on the concepts, design, and implementation of mobile applications. One of the primary challenges in the development of AR-based educational apps is the lack of standardization [13],[14] in interactions. The number of interactions in an educational app is not very specific [15], and this fragmentation makes it difficult for developers to create apps that are compatible with different subjects. This leads to higher development costs and longer development times. This lack of standardization can also lead to two other constraints:

- **Usability and user experience:** AR-based educational apps often require a high level of interaction from users, and the apps can be complex to navigate. This complexity can result in frustration and disengagement, leading to low user adoption rates.
- **Integration with existing learning management systems (LMS):** Integrating AR-based educational apps with existing LMS can be challenging, as specialized software development kits (SDKs) are required for this purpose, which may not be compatible with existing LMS platforms.

These challenges can lead to higher development costs, longer development times, and low user adoption rates. To address them, it is important for developers to work together to develop

standardized interaction frameworks, which would make it easier for developers to create compatible apps to improve the usability and learning experience of AR-based educational apps. Additionally, there are a number of other challenges that need to be addressed in order to develop effective AR-based educational apps. These challenges include: a) The need for high-quality 3D models and animations, b) The need for accurate tracking and positioning user log for efficient data management, and c) The need for effective pedagogical design to maximise the app's utility.

2.3. Research Gap

Based on the existing literature, the following questions were considered for this research:

- **RQ1:** Which features should exist in educational apps that can be generalized across disciplines?
- **RQ2:** Can these features be combined together in a system architecture framework to standardize text book companion app design?

3. The proposed System Architecture Design Framework

3.1. i-BioVARse app

As a prototype design, a markerless augmented reality (AR) app [16] called "i-BioVARse" was developed for Biology students of grades 10 and 11 using Unity 3D[1]. The demo app is available at this link[2]. The list of interactions is available at table 1.

i-BioVARse was compared against the official app of the NCERT (National Council of Educational Research and Training) Biology book available from the DIKSHA portal[3] and the epathshala AR app portal[4]. DIKSHA app is a standard textbook companion app while epathshala AR focuses only on AR content. The instructions to use the official DIKSHA app can be obtained from here[5]. The topics chosen for the experiment were: Heart (Grade 11, Chapter 18), Human Eye (Grade 10, Chapter 11), Lungs (Grade 11, Chapter 17). Figure 1 shows the proposed System Architecture Diagram and the infographic description of the i-BioVARse app.

3.2. Description of the System Architecture Design

The proposed system architecture design consists of five major modules, namely: (i) Augmented Reality (AR) Module, (ii) Assessment (Quiz) Module, (iii) In-screen Active Reading (Notes) Module, (iv) Ask me Anything (GPT based QnA) Module, and (v) Hosting and Analytics Platform (Google Firebase) Module. These modules independently perform specific interactions based on some pre-defined affordances. The user interface (UI) consists of a main menu, a quiz game, a note-taking feature, and an "Ask Me Anything" feature. The main menu allows users to select

[1] https://unity.com/unity/features/ar
[2] https://github.com/SPARTA-Research-Group-ET-IITB/i-BioVARse
[3] https://diksha.gov.in/getapp/
[4] https://play.google.com/store/apps/details?id=nic.ncert.ciet.epathshalaarhl=en
[5] https://ncert.nic.in/textbook/pdf/instruction.pdf

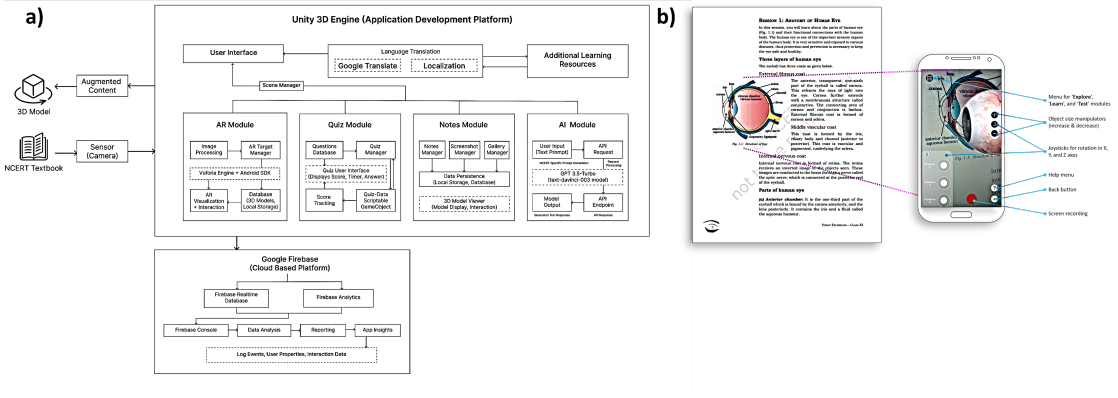

Figure 1: a) System Architecture Design and b) Infographic description for i-BioVARse Mobile application.

from the different features of the app. The quiz game allows users to test their knowledge of Biology. The note-taking feature allows users to take notes about the 3D models. The "Ask Me Anything" feature allows users to ask questions about Biology and receive answers from a large language model.

- **Augmented Reality Content Module:** This module is responsible for creating and displaying 3D models of biological objects. The module uses the Vuforia augmented reality platform[6] to track the position of the user's device and overlay the 3D models on the real world. The module also includes a variety of features that allow users to interact with the 3D models, such as a) rotation, b) zooming, and c) panning.
- **Assessment (Quiz) Module:** It provides users with a way to test their knowledge of Biology through a series of questions about Biology. The questions are presented to the user in a multiple-choice format. The user can select the answer they believe is correct. The quiz module keeps track of the user's score and provides feedback on their performance. The quizzes are designed to be challenging but fair, and they provide users with feedback on their performance.
- **In-screen Active Reading (Note Taking) Module:** This module is responsible for providing users with a way to take notes and screenshots of the 3D models and other content in the app. It also includes a gallery where users can store their notes and screenshots, and allows users to type notes about the 3D models in addition to taking their screenshots, which can be saved to the user's device or shared with others.
- **Ask me Anything Module:** The "Ask Me Anything" feature allows users to ask questions about Biology and receive answers using a large language model (GPT 3.5) [7]
- **Hosting and Analytics Platform (Google Firebase) module:** The hosting and analytics platform (Google Firebase [8]) [17] module is responsible for hosting the app and

[6]https://www.ptc.com/en/products/vuforia/vuforia-engine/ar-app-development
[7]https://platform.openai.com/docs/models/gpt-3-5.
[8]https://firebase.google.com/products/analytics

Table 1
Key interaction and affordance features - NCERT DIKSHA vs i-BioVARse

Affordance	Interaction	NCERT DIKSHA	i-BioVARse
Immersive Learning	AR Content	QR based	Markerless
	Voice over Narration	Not Available	On demand against the current page
	AR Content Navigation	Static	Dynamic, 360°rotation with zoom
	Animated Content /Video	Static	Dynamic, Can be interacted with through note taking
Active Reading	Note taking	Not Available	Note taking option with screenshot capacity
	Record of Interaction	Not Available	The entire interaction with the app can be recorded and shared
Assessment	Quizzes Test	Available	Available

providing analytics data about user behavior. The module uses the Google Cloud Platform to host the app and store its data, and it includes a variety of analytics features that allow developers to track user activity and identify trends.

4. Study Design: Usability Assessment of i-BioVARse App

The System Usability Scale (SUS) was used to assess the usability of the i-BioVARse app. The usability of i-BioVARse was compared with the standard textbook companion apps available from the DIKSHA and ePathshala portals. In this study, 11 participants were provided with the applications and were asked to interact with them for a limited duration. Their feedback was recorded through a web platform. This interaction was focused on various application features, such as the AR model, multimedia content, and MCQ assessments. The average SUS score for i-BioVARse was 85.45 which is good usability, and it was 42.04 for the standard textbook companion app, which has fair usability. This result is indicative of a better usability for i-BioVARse application. Table 1 shows the comparison between i-BioVARse and the official textbook app (NCERT DIKSHA).

5. Future Work and Conclusion

The study presented here has demonstrated the effectiveness of i-BioVARse as a learning tool. However, further studies are needed to investigate the long-term effects on student learning outcomes. One area to look into is collaborative learning through apps as classroom activities are often collaborative in nature. Addition of these features would make the app more engaging and effective, and would allow students to learn from each other by sharing their ideas, working in teams to solve problems, and learn from each other in a more meaningful way.

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