Supporting Learning Through Affordance-Based Design: A Comparative Analysis of "BioVARse" and a Standard Textbook Companion Application in Biology Education

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Abstract: Textbooks as an educational artefact has evolved immensely with technology, especially through mobile applications. When used in conjunction with textbooks, mobile applications have the potential to provide a unique set of affordances to support learning. This paper presents the design of "BioVARse", a textbook companion app for Biology subjects that provides these affordances to the learners. A comparative analysis of these learning affordances with a standard textbook companion application is presented, and a pilot study for assessing the usability is also performed. The preliminary results indicate a significantly higher usability of BioVARse, when compared to the standard application. Additionally, the paper also discusses the possibility of improving the learning experience through an affordance-based design of a textbook companion app.

1. Introduction and Background

Textbooks are the primary learning materials that are used for studying a subject by learners. Appropriate technological enrichment can provide access to static and dynamic content, such as in Phygital textbooks (Prajapati & Das, 2023), which can impact learning outcomes of an individual, such as their reasoning behaviour (Karnam et al., 2020). Currently, textbooks are enriched with dynamic content through the quick response (QR) codes or through Augmented Reality (AR) markers on the printed textbook page (Danaei et al., 2020; Ghaem Sigarchian et al., 2018). This content is then accessed through digital devices, such as mobile phones, which can be termed as the textbook companion applications.

In Science, topics in Biology (and similar subjects) require visualisations for learning of various concepts, as inappropriate visualisations may result in development of misconceptions (Yusof et al., 2020). AR can be used in this situation to effectively facilitate immersive visualisations using dynamic content, and it can be provided to learners through a mobile application that can be used in different learning scenarios (Susilo et al., 2021). Companion apps that are available to the learners primarily focus on the content accessibility, failing to address the issue of their integration into learning activities.

Consideration of affordances that are crucial in learning can be an important aspect that should be considered for such applications (Hammond, 2010). In human-computer interaction, "affordance" refers to the perceived or actual action possibilities an object offers a user. Though lacking a universal definition, this work defines it as the set of interactions facilitated by a tool that supports learning. This study details the design of a textbook companion app (BioVARse), based on affordance analysis and comparison with a standard app, and elucidates a usability study of these application.

2. Design Space for BioVARse

A markerless AR app, 'BioVARse,' was developed using Unity 3D, for 10th and 11th-grade students studying Biology. It covers five NCERT curriculum topics, with textbook diagrams coded as markers for 3D models. These topics were: "Body fluids and circulation", "Breathing and exchange of gases", "Digestion and absorption", "Excretory products and their elimination", and "Structure of human eye". The name BioVARse combines concepts of metaverse, virtual reality, and augmented reality. The system architecture, detailed in Figure 1, elucidates the integration of AR, Quiz, and App modules. The prototype is accessible on Github[1], and the topics were selected from federal textbooks based on open-source AR content availability, and resources availability on DIKSHA . The key affordances of BioVARse applications specifically designed to support learning of the topic are: Note-taking, Voice-over narration of the text, Access to 3D AR content, Formative assessment for the topic, Access to static content, and Sharing of information. The affordances due to mobile devices were same for both applications, i.e, DIKSHA and BioVARse, which are the ability to interact with learning content through touch, scroll, text input, etc. (Berthelsen & Tannert, 2020). The affordances (listed above) were facilitated to the user through three primary components of the app, which are: a) Learn (for static and dynamic content accessibility), b) Explore (for engagement with content), and c) Test (for formative assessments and feedbacks). These affordances are elaborated in Figure 2 below, which were used as a comparison metric for both the applications.
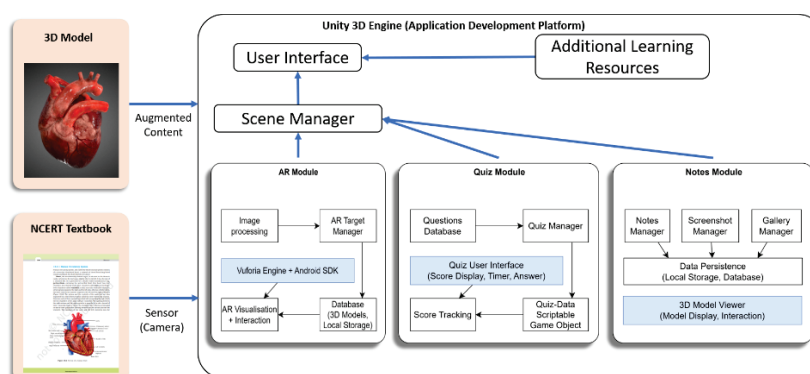

Figure 1. System architecture of BioVARse application.

3. Study Design and Results

The usability of the BioVARse app was assessed using the System Usability Scale (SUS), chosen for its reliability and ease of use. Eleven participants (chosen through convenient sampling) interacted with the app on the topic 'Human Heart (Body fluids and circulation),' and their SUS survey responses were recorded online. Instructions were provided, and users were encouraged to engage with AR models, multimedia content, and assessments. The SUS survey was administered for both the BioVARse and NCERT DIKSHA apps, and usability scores were compared using the Mann-Whitney U test, revealing a significant difference **(U = 13.5, p < 0.005**). The results indicate acceptable usability for BioVARse and poor usability for the standard DIKSHA application.

	Key learning affordances	BioVARse	DIKSHA
1	**Note Taking:** It involves learners' active engagement with texts by writing short texts, which the learner thinks is important (or relevant) to the subject. Mobile devices due to their portability facilitates easy note-taking (Pyörälä et al., 2019), and learners can engage in such activities during in-class or after-class sessions (Chen, 2021).	*Supported through a dedicated feature available in the explore section of the application. It can be used alongwith screenshots from the application, and manipulations with the 3D model can also be recorded.*	*NA*
	a) Text based notes, b) Images, c) screen recording (s)	Available	Not available
2	**Voice-over narration of the text:** it allows the transmission of textual information into different modality, i.e. audio to the learner. This feature allows the learner to opt for a different mode of engagement with the content.	*Available through a dedicated option on the current screen that the user can access anytime.*	*NA*
	a) Audio for on screen text content	Available	Not available

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[1] BioVARse: https://github.com/SPARTA-Research-Group-ET-IITB/BioVARse

#	Affordance	App 1	App 2
3	**Access to 3D AR content:** 3D models that can be manipulated through hand gestures can provide enhanced spatial perception of the object, which is mentioned in the text (Swamy K L et al., 2018).	*Full range of interactions through a dedicated on-screen buttons such as 360 degree rotations with pan and zoom are available to the user.*	*The models can be interacted with in a limited way with no cues provided to the user.*
	a) 3D Models of the diagrams	Available	Available
		(markerless AR)	*(QR code based)*
	b) 360 rotation manipulation, c) Pan and Zoom manipulation	Available	Not available
4	**Formative assessments:** Operationalised in the form of a set of multiple choice questions with four options, which can be mediated by an instructor in the classroom or could be used independently by learners with the primary goal of providing feedback on the learning of the content (Bennett, 2011).	*Facilitated through MCQs after every topic*	*Facilitated through MCQs after every topic*
	a) MCQ	Available	Available
	b) Descriptive questions	Not available	Not available
5	**Access to static content: :** interaction with texts and images in the textbooks through viewing on mobile screen, navigating across and within textbook page, resizing, etc are also afforded, similar to other digital learning materials (Berthelsen & Tannert, 2020)	*Textual content of the topic is available separately to the user along with the option to download the PDF of the textbook chapter*	*Available in the form of a PDF document of the textbook*
	a) PDF document of textbook page	Available	Available
	b) Isolated topic text	Available	Not available
6	**Sharing of personalised information:** personalised information such as screen recordings, and notes can be shared by the students with their peers, hence, providing ways to collaborate in and outside the classroom environment.	*Personalised information (such as notes, recordings, etc.) can be shared by user to their peers*	*Only the standard content can be shared by the user*
	a) page link(s)	Available	Available
	b) screen recording (s)	Available	Not available
7	**General affordances**		
	a) Navigation between pages, b) Access to videos for the topic, c) Help (application related)	Available	Available

Figure 2: Key learning affordances and how they are facilitated in the two mobile applications

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