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RESEARCH ARTICLE

High School Students' Engagement in Biology in the Context of XR Technology

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This work involved human subjects or animals in its research. Approval of all ethical and experimental procedures and protocols was granted by the Institutional Ethics Committee of An-Najah National University, in line with the Declaration of Helsinki.

ABSTRACT With Extended Reality (XR), it is possible to enhance our real-world experiences through a fusion of immersive and interactive technologies. In the present research, the researchers intended to study high school students' engagement in Biology learning in the context of XR. Fourteen tenth-grade students who learned the biological topics of the cell and the heart participated in the research. During the selection process, consideration was given to the students' readiness to participate in the program. The researchers collected data via interviews and observations. The interview questions were related to the four types of engagement: The behavioral, the cognitive, the emotional, and the social. The observations were used to triangulate the interview-based data. To analyze the data, the researchers used deductive and inductive content analysis. The research results indicated the XR context encouraged the participants to engage in four types of engagement: cognitive engagement (learning perception, learning assessment, learning regulation, learning application), emotional engagement (learning sufficiency, affection for learning, and learning motivation), social engagement (interaction and communication), and behavioral engagement (achievement and good classroom behavior). The observations results supported the results from the interviews.

INDEX TERMS Extended reality (XR), students' engagement, high school, biology lessons.

I. INTRODUCTION

A. EXTENDED REALITY (XR)

This research documents several key contributions in the field of Extended Reality (XR). XR technology is characterized as curating experiences through technology that seamlessly merges both digital and biological realities [1], [2]. Despite employing a wide array of software and hardware tools, Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR) converge on three core attributes: immersive experiences, a sense of presence, and interactive capabilities [3]. Extended Reality (XR), an amalgamation of these immersive and interactive technologies, holds the potential to either enhance or alter our experiences in the real world [4]. The term also covers software, hardware, and electronic tools that enable users to experience digital virtual reality (VR) in conjunction with their physical environment [5]. In addition to those mentioned above, Extended Reality (XR) can generate motivating and engaging educational experiences, fostering enthusiasm for learning among students, and enabling the exploration of otherwise inaccessible perspectives while refining problem-solving skills. Despite its substantial advancements, ongoing innovative developments promise continual enhancement of existing technologies and the introduction of novel solutions [6].

Furthermore, it belongs to the class of augmented virtual reality technologies that convey complex scientific information, aid in comprehending abstract ideas, and make scientific phenomena that are challenging to notice without technology clearer. The benefits of using XR technology as an application of contemporary information technology increase students' engagement in learning [7], [8], [9], increasing their motivation to learn. Additionally, XR technology significantly facilitates students' understanding of concepts related to new

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topics and motivates learners to exert effort and meet their educational obligations within specified timeframes [10].

B. STUDENTS' ENGAGEMENT IN XR TECHNOLOGICAL ENVIRONMENT

Extended Reality (XR) technology enables students to manage their learning pace and strategically use tactics, promoting motivation, interaction, communication, and collaboration with educators [4], [11]. Cevikbas and Kaiser propose that XR technology boosts student engagement, enhancing learning outcomes, comprehension, and academic performance and potentially decreasing dropout rates and aggressive behaviors [12]. XR technology uses avatars and holograms to create realistic learning environments [2], [6], [13]. By the same token, XR enriches experiential learning, as described by Kolb [14], by broadening the range of tasks and activities fostering concrete experiences that were previously unattainable [15], [16]. Previous scholars also discussed that Extended Reality (XR) technology significantly enhances the cyclical learning process of concrete experience, reflection, abstract conceptualization, and active experimentation [17], [18]. The process involves self-driven practical experiences, multi-perspective analysis, goal setting for new idea conceptualization, and hypothesis testing in new contexts. XR technology offers immersive experiences that stimulate reflection, aid in event interpretation, enable comparison with pre-existing knowledge, and bolster active engagement in problem-solving and decision-making, thereby propelling knowledge development [19], [20].

Learning engagement is a gauge of an individual's sufficient motivation to invest themselves in learning wholly and is measured by the level of cognitive effort, or interaction students deploy in educational activities to attain intended learning outcomes [21], [22], [23]. Previous work by Finn et al. [24] defines student engagement as a collection of intentional behaviors indicating active, meaningful participation in learning activities. It is a complex concept encompassing emotional, behavioral, and cognitive facets [25], [26]. Emotional engagement involves students' emotions during tasks, including interest and frustration. Behavioral engagement concerns students' effort, persistence, and task completion.

Conversely, cognitive engagement relates to students' strategies to main their work [26]. Marks and Newmann distinguish emotional engagement as learners' feelings towards learning and behavioral engagement as noticeable behaviors denoting effort and learning achievement [27], [28]. According to Finn's model, student engagement integrates both behavioral elements (like active learning attitudes such as questioning or task completion) and emotional elements (like feelings related to learning, such as community engagement or a sense of belonging) [24], [29]. In the same fashion, cognitive engagement, linked to learning performance measures like test scores and learning confidence, represents learners' investment in their thoughts, efforts, or learning strategies [23], [30]. Engagement, which encompasses curricular and extracurricular activities, spans behavioral, psychological, and cognitive aspects [29]. The recent literature underscores the profound benefits of Extended Reality (XR) technology on various facets of learner engagement, notably cognitive, emotional, social, and behavioral [31], [32], [33], [34], [35]. It enhances cognitive engagement via evaluative feedback. Thereby, it increases metacognitive awareness and fosters self-regulation [35], [36]. Studies further assert that augmented interaction with immersive environments augments learners' control and active participation, with feedback playing a critical role in social engagement that reciprocally impacts emotional engagement [37], [38], [39]. This amalgamation of social and emotional engagement fosters a favorable emotional environment and bolsters cognitive engagement.

Extended Reality (XR) technology has been found to positively impact emotional engagement among students by enhancing their enjoyment and motivation [40], [41]. It is noted that students' sense of responsibility for their learning escalates their emotional engagement [42]. Furthermore, XR bolsters social engagement through increased interaction and collaboration [35], [43]. Technology generally facilitates enhanced behavioral engagement by promoting positive peer interactions and proactive learning [38].

Based on the sort preview above, the present study employs experiential learning, promoting in-depth knowledge acquisition through exploration, which is well-suited to the unique capabilities of Extended Reality (XR). XR offers exceptional opportunities for exploration and perception, owing to its immersive nature [17], [18]. Users are able to view problems from both egocentric and exocentric perspectives within the virtual environments, promoting knowledge acquisition and lateral thinking, respectively [44]. Figure 1 shows the conceptual framework to elicit students' engagement by developing Extended Reality applications using Kolb's Experiential Learning Cycle.

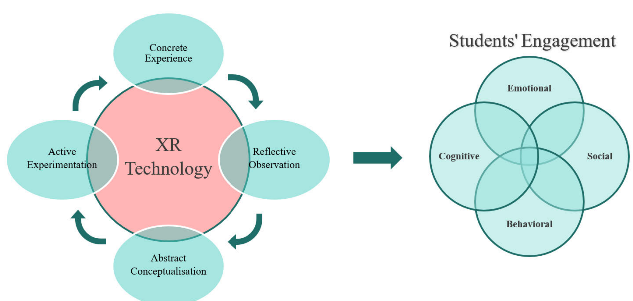

FIGURE 1. Conceptual framework to elicit students engagement by development of XR applications using Kolb's experiential learning cycle.

While many studies have addressed technology integration in education, there is a distinct gap in the literature, specifically concerning the influence of Extended Reality (XR) technology on student engagement in high school Biology classes. Many previous investigations have primarily centered on the broader implementation of technology in the educational domain. They neglected the nuanced effects of immersive tools, such as XR, on student engagement within science instruction. This omission becomes particularly glaring given XR technology's burgeoning role in modern pedagogical environments. As such, this study endeavors to bridge this evident research lacuna by scrutinizing the ramifications of XR technology on student engagement, especially within Biology instruction. Intending to direct educators towards innovative pedagogical strategies, the study zeroes in on XR technology's capacity to invigorate various engagement facets—behavioral, emotional, cognitive, and social—within Biology lessons. This kind of focus not only offers a fresh lens on the effectiveness of XR in enhancing educational outcomes but also sets the stage for analogous explorations across different academic fields and student demographics. Consequently, the primary ambition is to dissect the manifold impacts of XR technology on the multifaceted engagement behaviors exhibited by secondary school students during Biology instruction. This endeavor culminates in the pivotal research question:

What is the impact of XR technology on the engagement of secondary school students in Biology?

This study employed a systematic methodology to address the research question. Using observations and semi-structured interviews, a purposive sample of 14 tenth-grade students who interacted with XR technology in Biology was targeted. The interview structure was rooted in the study's theoretical framework, encompassing thirteen queries that spanned emotional, behavioral, cognitive, and social engagement dimensions. Following rigorous data analysis based on these engagement indicators, four core themes emerged, which directly addressed the study's primary inquiry regarding the impact of XR technology on students' engagement in Biology. Furthermore, it employs a combination of deductive and inductive strategies for data analysis incorporated within the thematic analysis methodology. This approach allows for a holistic depiction of students' engagement as outcomes of their experiences with XR learning.

II. METHODOLOGY

A. STUDY PARTICIPANTS

Fourteen tenth-grade students from Shufat Comprehensive School for Boys in Jerusalem were investigated. The decision to select Shufat Comprehensive School as the research site was influenced by its advanced technological infrastructure and the presence of biology educators who have undergone specialized professional development programs focused on extended reality technology. Participants were chosen through a purposive selection strategy based on their willingness to participate and showed interest in science, biology, and XR. To ensure the participants' privacy and compliance with research ethical standards, the fictive names of the students were utilized during the dissemination of results.

The participant selection process utilized purposive sampling, a strategy favored when the research intention is to delve into and comprehend a specific subject, necessitating a sample capable of yielding a substantial data volume [45]. Initially, twenty students were selected, with interviews conducted with fourteen of them. Additionally, a waiting list comprised six students who could step in should any peer withdraw from participation for any reason. Compliance with the requisite participation criteria was paramount to the study's success and data quality assurance. By selecting the most appropriate participants aligned with the study's objectives, the researchers aimed to uphold the integrity of the study.

B. LESSON IMPLEMENTATION PROCEDURE

Following Majgaard and Weitze [17] and Lai and Cheong [13], the researchers implemented an application of Kolb's Experiential Learning Cycle, incorporating XR technology, in Biology lessons:

1. Concrete Experience (CE): Through an interactive display, students were equipped with VR glasses to engage with a 3D representation of a biological structure, such as a cell or cardiovascular system. This immersive experience allows for a detailed examination of the model, supported by navigation within the simulated environment. The Mozaik application facilitates direct interaction with various model components, providing a hands-on learning experience.
2. Reflective Observation (RO): Students engaged in a reflective exercise following the VR interaction. Peer discussions encouraged sharing individual observations and insights, fostering collective reflection. The teacher facilitated these discussions, prompting students to articulate their impressions, questions, and newly acquired knowledge.
3. Abstract Conceptualization (AC): After the reflective phase, the teacher elucidated the theoretical dimensions of the examined biological structure, bridging the gap between hands-on experiences and abstract concepts. The Mozaik application is utilized to visually represent and facilitate the understanding of these abstract notions, enabling learners to establish connections with their first-hand experiences. This step strengthened comprehension and promoted the application of theoretical knowledge to practical experiences.
4. Active Experimentation (AE): In the final step, students revisited the virtual model for active experimentation within the virtual environment. Drawing on their newly acquired knowledge, they manipulated the model, identifying parts, explaining functions, or predicting outcomes of changes within the model. This hands-on experimentation allowed learners to validate their understanding, develop problem-solving skills, and engage in scientific exploration.

C. DATA COLLECTION TOOLS

In this research, a blend of semi-structured interviews—both in-person and remote—and observation of activation and explanation sessions was employed to gather requisite data for analysis. The interviewees constituted a cohort of students whose Biology instruction incorporated XR technology, including 3D interactive boards and virtual reality glasses. The objective of these interviews was to glean data regarding the engagement of secondary school students in Biology instruction facilitated by XR technology.

A limited number of the interviews were undertaken in person within the school's computerized lab, where all necessary study apparatus were present. Specific queries were posed during the interviews, with the proceedings recorded in adherence to research ethics standards. Alternatively, a series of interviews were conducted remotely via the Zoom platform [46], following a semi-structured interview design and procedure [47].

The interview instrument encompassed thirteen questions derived from the research questions at the heart of the study and segmented across four primary dimensions associated with the study's underpinning theoretical framework. These dimensions included emotional, behavioral, cognitive, and social engagement. The interview questions were reviewed and validated by experts in the field.

D. DATA ANALYSIS TOOLS

The analytical process for the research data hinged on the four markers of student engagement, namely cognitive, behavioral, emotional, and social engagement, necessitating comprehensive examination and analysis [12], [48]. Afterwards, the data acquisition process originated with the student interviews, extending throughout the analytical procedure as informed by data saturation. While analyzing existing data, the researchers were compelled to conduct additional interviews to supplement the existing data. Saldana's [49] proposed MAXQDA 2020, a computer-assisted software, was employed during the coding process. MAXQDA is renowned as a qualitative data analysis tool that facilitates the collection, duplication, organization, analysis, visualization, publication, and retrieval of earlier data [50], [51].

E. DATA ANALYSIS PROCEDURES

Following the methodological guidance provided by Braun and Clarke [52], the data analysis process was undertaken in six procedural stages, as delineated in Figure 2.

The data within this research was scrutinized utilizing two-cycle coding procedures and thematic analysis, a technique underscored for its significance in several studies [45], [53]. These studies emphasize the utility of coding processes wherein researchers cherry-pick data of relevance, aligning it with the study's theoretical framework and research questions. During the initial cycle, the types of coding employed encompassed in-vivo, emotion, descriptive, and evaluation (refer to Table 1).

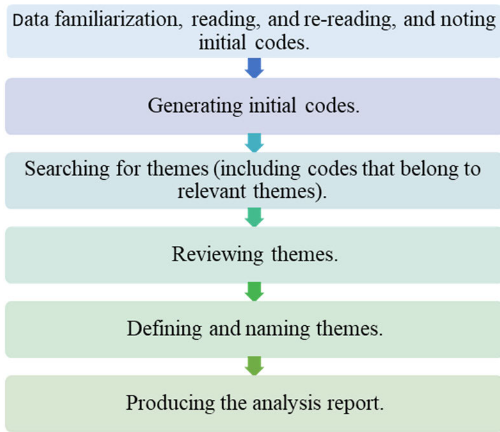

FIGURE 2. Data analysis procedure stages.

TABLE 1. Examples of first-cycle coding.

In-Vivo Coding	Emotion Coding	Description Coding	Evaluation Coding
"I wanted to explore things " further."	Enjoyment of learning	Clarity of the image	Satisfaction with the tool (-)

The subsequent cycle, often called pattern coding, was executed upon completing the initial cycle coding analysis. Pattern coding aggregates data portions into categories or themes, encapsulating and interpreting meanings from codes generated during the first cycle [53]. Miles et al. [53] furnish a synopsis dictating the typical usage of pattern coding for formulating categories or themes and discerning connections between concepts or theoretical constructs (p. 80). With the research questions and study objectives as a basis, the researchers developed categories and sub-themes throughout the second coding cycle. These categories were sorted by the categories spawned from the theoretical framework, culminating in 36 categories within cognitive, emotional, behavioral, and social engagement themes. These codes were scrutinized, compartmentalized, and contrasted using focused coding, consolidating the 36 categories into ten sub-themes. A consensus on the nomenclature of these sub-themes was attained within the research team [46].

F. CODING APPROACH

In this research, a combination of deductive and inductive strategies for data analysis was adopted and incorporated within the thematic analysis methodology [54]. The deductive approach was deployed to interpret the participants' responses, offering a holistic depiction of their behavioral, emotional, cognitive, and social engagement as outcomes of their experiences with XR learning. This interpretation was guided by the study's theoretical framework [12], [48]. The deductive approach at this stage leaned on descriptive coding congruent with the study's epistemological queries. Descriptive coding entailed affixing labels to the highlighted data extracted from the participants' narratives in a process known as in vivo coding. These labels, concise summarizing phrases, encapsulated the intended central meanings of the qualitative data. They facilitated the creation of a valuable topic list for indexing and categorizing, ultimately forming categories corresponding to the themes aligned with the research questions [49].

The second segment of the first cycle data analysis drew upon the inductive approach to categorize and disprove responses, suggesting new categories related to the four engagement themes. As demonstrated in the deductive approach section, these categories were not explicitly articulated in the foundational theoretical framework the study built on [55]. To distinguish their potency or feebleness, respectively, evaluation coding was applied to the pertinent coding categories associated with emotional engagement by attaching a (+) or (−) sign [56].

In this research, the unit of analysis is the "theme," which is a phrase or sentence that delineates the unit of analysis tied to the meaning or nature of the data. It characterizes and organizes potential observations that elucidate aspects of the studied phenomenon [57]. It classifies data into sub-themes that systematize recurring ideas [58]. The thematic analysis enables categories to emerge from the data, which are connected to the study's theoretical framework and determined before conducting the interviews. This analysis aids in reducing the number of themes to be examined and discussed in the results and discussion section. A "code" is a word or short phrase that symbolically designates a summarizing, salient, essential, and/or influential attribute of a segment of language-based or visual-based data [49].

In the present study, the unit of analysis consisted of phrases, for instance: *"Through the image, oh, when you touch it, you remember it more,"* and *"The thing I don't like is the dizziness caused by the VR headset."* The socio-constructivist theory was utilized to interpret students' engagement in the XR learning experience. This was discerned through students' engagement in learning, which related to cognitive aspects such as error noticing and correction, social elements such as peer interaction, and emotional factors such as learning motivation and focus [12]. Consequently, a deductive coding book was developed based on these domains, as demonstrated in Table 2, following the deductive approach of Crabtree and Miller [59] by applying theoretical frameworks to build the coding book (Codebook) and then linking the codes to the texts. The four dimensions of engagement (cognitive, behavioral, emotional, and social) were included in the coding book to examine students' engagement in learning Biology through XR technology.

TABLE 2. Coding book.

Coding name	Definition	Example
Cognitive Engagement	Thinking and willingness to tackle challenging ideas and skills.	"By using this technology, he can think and deduce the answer for himself without the teacher directing us."
Behavioral Engagement	The learner's active attitude towards learning	"It makes us always pay attention to the teacher and not play in the classroom."
Social Engagement	Participation, interaction, and collaborative work in lessons and learning activities	"The participation in this class was more than any classes I have seen."
Emotional Engagement	Positive feelings about lessons and learning activities	"Very pleasant experience"

G. ETHICAL RESEARCH PROCEDURES

According to Lincoln and Guba [60], four main pillars underpin the quality and dependability of qualitative research. These include credibility, mirroring the concept of internal validity in quantitative studies; transferability, an equivalent of external validity in the quantitative realm; dependability, analogous to reliability in quantitative research; and confirmability, a match for objectivity in quantitative studies [61].

Several strategies were employed in this research to safeguard the reliability and quality of the research procedures and outcomes. A triangulation strategy was utilized to establish credibility, which entailed using multiple sources in the investigation. These sources might include deploying various methods to examine the research subject or using diverse data-gathering instruments like interviews and observations. Gray [62] underscored the inherent challenges in ensuring the validity of semi-structured or open-ended interview tools due to their adaptive nature. These types of interviews often generate new questions informed by participants' responses, questions that may not have been foreseen by the researcher and might not be present in the extant literature, rendering them somewhat unpredictable [62]. To fortify the quality of the present research, the researchers held multiple deliberative sessions to scrutinize the suitability of the interview questions in relation to the research aims and subject matter. The theoretical literature formulated these interview questions, specifically referencing the works of Cevikbas and Kaiser [12] and Cropanzano and Mitchell [48].

Regarding the criterion of transferability, the investigators reinforced the results with verbatim excerpts from participants' interviews. Furthermore, they juxtaposed the findings of this research with those of previous studies on similar topics, thereby strengthening the evaluative standards, the data quality, and the research outcomes' validity [62]. The investigators also established rigorous selection criteria for the sample to guarantee the fitting selection of participants in relation to the research goals. A deliberate sample of 14 tenth-grade students was chosen from the Shufat Boys' Secondary School, part of the Jerusalem Schools. These participants, averaging 16 years of age, had engaged with XR technology in Biology classes and were articulate in expressing their perspectives and emotions, aptly responding to the researchers' queries and achieving the research aims. Gray [56] advises that to ensure transferability, a research sample should consist of no less than 12 participants, and the interview duration should be approximately 30 minutes or similar, reaching a saturation point - a stage when additional data doesn't contribute any new information. This research adhered to these parameters with a sample size of 14 participants and interviews lasting between 25 to 30 minutes.

To ensure dependability per Lincoln and Guba's [60] recommendations, the researchers independently analyzed the data and then convened to discuss the analysis results and achieve consensus on the codes and principal themes to be exhibited in the outcomes. The percentage agreement calculated via Cohen's kappa coefficient between the researchers was 0.85, denoting near-perfect consensus as per Landis and Koch's categorization [63]. Additionally, the coding process and the extraction of themes from the interviews were elucidated and detailed utilizing MAXQDA software, a tool specifically designed for qualitative data analysis.

To enhance the confirmability of their study, the researchers engaged experienced colleagues and professors at An-Najah National University to review and provide feedback on their interview questions, resulting in further refinements [64]. They carried out independent data analyses to help mitigate biases, a practice endorsed by Denzin and Lincoln [64]. The Audit Trail method was employed to document all applied procedures and decisions, which reduced potential bias and increased the study's trustworthiness [64]. To achieve the criterion of authenticity, the researchers employed the two-cycle coding and Thematic Analysis procedures, as well as the continuous comparison method, which reduces the occurrence of inaccurate analysis. Additionally, agreement among the researchers was calculated when presenting the results, and different qualitative studies were followed for analysis [65].

Regarding the criterion of saturation, the researchers halted the interview process following the completion of interviews with 12 participants. The absence of fresh insights influenced the decision, as reiterated data signified the potential for uniform outcomes from subsequent data collection. Two additional interviews were conducted to increase validation, leading to analogous data repetition. Consequently, the point of data saturation was successfully reached [66], [67].

III. RESULTS

The interview analysis from the research, aimed at investigating the influence of Extended Reality (XR) technology on high school students' engagement in Biology classes, yielded four primary themes: cognitive engagement, emotional engagement, social engagement, and behavioral engagement. These themes encapsulated 2 to 4 sub-themes, further diverging into 2 to 6 categories. The emergent themes and sub-themes, some of which align with theoretical literature and others unearthed during the coding process, are displayed according to their frequency of occurrence in the interview coding, as depicted in Figure 3. Figure 3 was exported from the MAXQDA 2020 software, the tool used for interview coding. In light of the research methodology, comprising the adopted procedures, data analysis, and ethical considerations, the research outcomes address the central research question: "What is the effect of XR technology on secondary school students' engagement in Biology?"

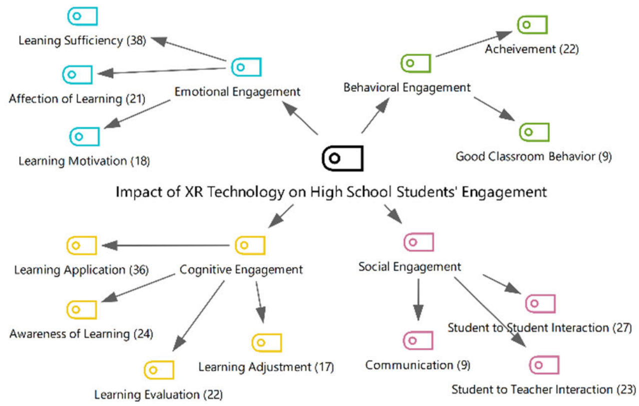

FIGURE 3. Codemap of interview results including codes' frequencies.

A. STUDENTS' INTERVIEW RESULTS

The students' remarks during the interviews, as Codemap depicted in Figure 3, were concentrated mainly on elucidating the impacts of XR technology on their engagement in Biology classes. The paramount emphasis was on Cognitive Engagement, which constituted 37% of the aggregate coding across varied themes. This was succeeded by Emotional Engagement (29%), Social Engagement (22%), and, ultimately, Behavioral Engagement (12%). In the subsequent sections, the researchers deliver an exhaustive dissection of each theme, including their associated sub-themes and the resultant categories. The word cloud in Figure 4 shows the codes with more frequencies in interview coding.

FIGURE 4. Word cloud for codes frequency.

1) COGNITIVE ENGAGEMENT

The cognitive engagement theme comprised four sub-themes: awareness of learning, application of learning, evaluation of learning, and regulation of learning.

a: LEARNING APPLICATION

This was highlighted in students' feedback about their capacities to store and retrieve information, recall and implement prior learning, and forge connections among distinct learning subjects. Student 12 delineated the rapidity of grasping information, saying, *"The information enters my mind faster and in a simpler way."* They also underscored the speed of recalling information, noting, "*It helps a lot in recalling information because it gets ingrained in my mind.*"

b: AWARENESS OF LEARNING

The students' responses related to using XR technology underscored their awareness of their learning in the Biology lessons. This was manifested in their ability to offer evaluative remarks and exhibit an understanding of learning objectives and the planning of their learning. For instance, Student 3 expressed, *"Now I know how to structure a plastid and what it's made of and its shape... it's much better than traditional lessons."* This comment illustrates that the students acknowledged the merit of the technology and its role in enhancing their learning experience.

c: LEARNING EVALUATION

This was underlined in the students' comments regarding the technology's role in helping them identify and rectify their errors, monitor their learning, the capacity to self-assess their acquired knowledge, and the ability to confirm or dispute the knowledge they attain. It also empowered them to tackle problems using diverse approaches. Student 1 expressed and evaluated their comprehension of new knowledge by stating, *"I misunderstood something about the lesson. Blood flow starts from the left atrium and ends in the right atrium, but I was confused. I revisited it using XR, and I understood it better."*

d: LEARNING ADJUSTMENT

This was apparent in the students' comments about how the technology fosters autonomous work. Student 4 mentioned, *"The student begins to explore, revisit information, and recall the images they have seen. Based on the questions, they begin solving them independently."*

2) EMOTIONAL ENGAGEMENT

The category of emotional engagement included three sub-themes: Learning Sufficiency, affection for learning, and learning motivation.

a: LEARNING SUFFICIENCY

The students' responses indicated their level of satisfaction with various elements of technology use, notably interactive boards, but some dissatisfaction was expressed, particularly concerning virtual reality (VR) glasses. Student 1 opined, *"The use of these glasses is straining to my eyes and not entirely beneficial. Using the interactive screen would be a superior and sufficient alternative."* Nevertheless, the students demonstrated enhanced self-assurance and readiness for class at any time. Student 3 disclosed, *"In a conventional class, I may feel disoriented and get somewhat nervous, but using XR, I feel prepared and retain everything."*

b: AFFECTION FOR LEARNING

The students' sentiments were palpable in their responses, with enjoyment being the predominant emotion, accompanied by enthusiasm, interest, passion, and readiness for learning. The students manifested delight during the Biology class, significantly enhanced by applying XR technology. Student 6 declared, *"The class was exceptional and fascinating. Everything was superb, and the class was top-notch... I was constantly eager to try it because when something is novel, it piques your curiosity, and you're inclined to experiment. It's captivating."*

c: LEARNING MOTIVATION

The students' responses indicated the impact of technology in fostering their motivation to learn, instilling a sense of responsibility and patience. As Student 11 shared, *"Through XR, things become more lucid, and my eagerness to assimilate more information has grown. I comprehend the issue through a realistic lens. The experience is not as immersive through the screen."*

3) SOCIAL ENGAGEMENT

The category of social engagement was partitioned into three sub-themes: student-to-teacher interaction, student-to-student interaction, and communication.

a: STUDENT-TO-STUDENT INTERACTION

The technology also positively impacted the students' interactions amongst themselves, fostering participation in group discussions and enhancing teamwork within the classroom setting. As expressed by Student 12, *"We started inquiring amongst ourselves about what we learned. We would discuss what transpired during the lesson, and after it concluded, we would quiz each other on what we gleaned from the lesson. Each one of us would disseminate the knowledge we accrued."*

b: STUDENT-TO-TEACHER INTERACTION

Responses from students underscored how XR technology facilitated enhanced interaction with their teachers. Student 8 observed, *"There is now greater interaction and collaboration between the teacher and the student. For instance, the teacher lets the students engage with the interactive board, and they collaborate, which is absent in traditional teaching methods... During the XR lesson, my participation rate might increase three or fourfold. I found myself more involved and active with the teacher."*

c: COMMUNICATION

Within the students' responses, instances of posing questions, providing answers, and seeking assistance and feedback were discussed. Student 10 shared, *"For instance, if a student was interacting with the XR technology and provided an incorrect answer, we would all pitch in and support them until they arrived at the correct response. We all participated."*

4) BEHAVIORAL ENGAGEMENT

The behavioral engagement category was divided into two sub-themes: achievement and positive classroom conduct. The students offered fewer remarks in this domain than in the preceding categories.

a: ACHIEVEMENT

The students' feedback indicated how the technology facilitated their learning process, helped them complete tasks related to the lesson, promoted continuous learning, improved their grades, and increased their effort and preparation for lessons. For instance, Student 9 stated, *"The board was greatly helpful. It displayed things clearly and in three dimensions. I could manipulate it to observe from all perspectives."* Speaking about the user-friendly aspect of the technology, the student mentioned, *"It was easy to utilize."*

b: GOOD CLASSROOM BEHAVIOR

The student feedback highlighted the technology's role in discouraging disruptive behaviors and promoting adherence to classroom rules. For instance, Student 1 observed, *"In a typical lesson, there may be bored or sleepy students, but here, it feels like students are coming to learn. It seems like a shift in the teaching methodology, something different from the norm."* Student 8 added, *"It's certainly different. In a standard lesson, a student might disrupt the class, or two students might start a conversation, causing interruptions. But here, as I mentioned earlier, because it's something novel, everyone wants to give it a try."*

B. STUDENTS' OBSERVATION RESULTS

This section presents a chronological account of the events for two biology lessons, emphasizing the dynamic interaction between the teacher and students, students' experience with the XR technology, and their interpersonal communications:

1) FIRST LESSON: "THE CELL"

1. Ms. Fidaa initiates class: *"Today, we're going to delve into an interactive way of learning by using Extended Reality (XR) tools... Please make sure you're comfortable with the XR headsets and know how to use the interactive TV."*
2. Omar raises a concern: *"Ms. Fidaa, what happens if I get lost in the virtual environment?"*
3. Ms. Fidaa reassures Omar: *"Don't worry, I will guide you through the process. Plus, you can always remove your headset to return to the classroom."*
4. The lesson begins with Ms Fidaa: *"Alright everyone, let's dive into a virtual eukaryotic cell."*
5. Students navigate the virtual cell and inspect various organelles.
6. Ali identifies an organelle. Ms. Fidaa comments: *"Excellent, you've located the nucleus. Now, let's explore more about its functions."*
7. Ali expresses his experience: *"It's almost like I can touch it!"*.
8. Students' enthusiasm increases, reflected by Tamer's exclamation: *"Ooh, teacher this is something incredible!"*
9. Khalid's statement: *"It's like we're inside the cell!"*
10. Transition to group activity. Ms. Fidaa instructs: *"Now, let's take a closer look at these cell components in our textbooks."*
11. As groups work with the Mozaik 3D application, Ahmed asks: *"Hey, can anyone see where the Golgi apparatus matches on the diagram?"*
12. Omar responds by pointing to the TV screen: *"Look, it's right there, see how it matches with our book diagram?"*.
13. Ms. Fidaa encourages bridge-building between 3D and 2D representations: *"Can you see how the 3D virtual representation matches with our 2D diagrams?"*
14. Ms. Fidaa introduces the interactive quiz: *"Let's test your understanding with a quiz. Instead of writing down the answers, point to the correct organelle in the virtual cell model."*
15. High levels of cognitive and behavioral engagement were observed during the interactive quiz.

The application of Extended Reality (XR) tools in the observed lesson "The Cell" provided a rich, immersive environment as shown in Figure 5, fostering multiple dimensions of student engagement (Line 1, Line 4). When students such as Omar expressed concerns about the novel learning environment, teacher reassurance helped facilitate a sense of comfort and safety, promoting behavioral engagement (Line 2, Line 3). Further, XR tools allowed students to navigate and interact directly with complex biological structures (Lines 4-7), bolstering cognitive engagement through active exploration and discovery. This was further amplified by emotional engagement, as reflected in Tamer and Khalid's enthusiastic comments about the immersive experience (Lines 7-8). Collaborative activities that encouraged the use of XR tools to complement traditional textbook learning facilitated cognitive and social engagement (Lines 9-11). This type of engagement enhances understanding and retention of learned material. By asking each other questions and sharing their insights (Line 10), students like Ahmed and Omar showcased peer learning as an important aspect of social engagement. Ms Fidaa's novel application of XR technology to transform a traditional quiz format into an interactive experience encouraged students to actively participate in their learning, thus strengthening their behavioral and cognitive engagement (Lines 12-13). Exploring the human heart system was a real-world application of theoretical

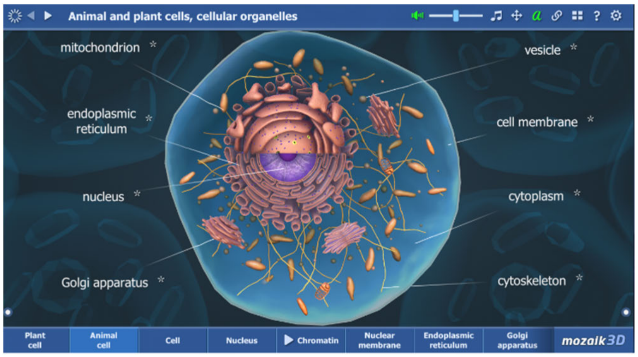

FIGURE 5. **Animal cell from Mozaik 3D software.**

concepts (Line 14), further deepening cognitive engagement. Sami's and Ibrahim's exclamations echoed the success of this pedagogical approach (Line 15), tying together the cognitive, behavioral, and emotional dimensions of engagement for a holistic learning experience.

2) SECOND LESSON: "HUMAN HEART"

1. Ms. Fidaa commences the lesson: *"Let's journey into a virtual human heart now."*
2. The students explore the virtual heart, observing various structures and functions.
3. Ali identifies a heart structure. Ms. Fidaa acknowledges, *"Good job, you've located the aorta. Let's understand its role more deeply."*
4. Ali shares their excitement: *"It feels like I can almost touch it!"* Figure 6 reveals that.
5. The class's enthusiasm heightens, as reflected by Akram's exclamation: *"This is so amazing!"*
6. Ms. Fidaa transitions to a group activity: *"Let's now compare the virtual heart structure with diagrams in our textbooks."*
7. While working with the Mozaik 3D application, Nader asks, *"Can anyone spot where the ventricles match up on this diagram?"*
8. Maher points to the 3D Interactive Screen in response: *"It's right here,"* as shown in Figure 7.
9. Ms. Fidaa encourages the connection between 3D and 2D representations: *"Can you all observe how the 3D model corresponds to our 2D diagrams?"*
10. Ms. Fidaa introduces activity through VR glasses: *"Let's point to the correct structure in the virtual heart model."*
11. As a concluding activity, Ms. Fidaa announces a virtual field trip to understand heart disease: "We will now journey into a heart affected by the disease. This will help you understand the real-world implications of heart disorders."
12. In response to the virtual field trip, Kareem exclaims, *"This really makes it clear how a blocked artery affects the heart!"*
13. Ahmed, a student, adds, *"I can see how important it is for the heart to function properly!"*

The classroom demonstrates a successful integration of Extended Reality (XR) tools in a biology lesson on the human heart, catalyzing various dimensions of student engagement. The commencement of the lesson through a virtual journey into a human heart (Line 1) represents an innovative pedagogical approach that helps stimulate cognitive engagement. Students' exploration of the virtual heart and subsequent interaction with various structures and functions further accentuate this cognitive engagement (Lines 2-3). The emotional engagement is discernible from Ali's excitement about the tangibility of the learning experience and is also echoed by Akram's enthusiastic response (Lines 4-5). These emotional reactions indicate a positive, affective response to the XR-enhanced learning environment, reinforcing the connection between emotions and meaningful learning. Incorporating group activity (Line 6) fosters social engagement, facilitating a space for peer interaction and collaborative learning. As students like Nader and Maher engage in a discussion to match virtual heart structures with textbook diagrams (Line 7, Line 8), they demonstrate a form of social engagement that enhances their collective learning experience. Finally, a virtual field trip to a heart affected by disease (Line 11) deepens cognitive engagement. This approach facilitates a real-world application of learned concepts, enabling students to gain a clearer, more concrete understanding of the practical implications of heart disorders (Line 12, Line 13).

FIGURE 6. **Students while using XR headsets.**

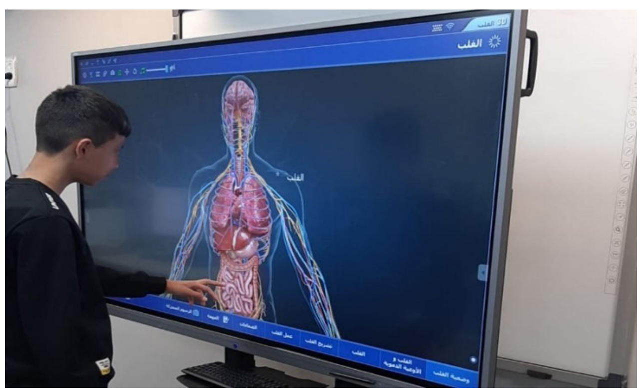

FIGURE 7. **Student while using 3D interactive screen.**

IV. DISCUSSION

Though educational research started to accumulate on digital simulations, virtual reality, and augmented reality [13], [68], [69], [70], educational research on XR in the science classroom is still in its infancy. The research primary objective was to explore the influence of Extended Reality (XR) technology application on several engagement domains, encompassing cognitive, behavioral, emotional, and social engagement, in the context of Biology education for high school students. This exploration was guided by the research inquiry: What is the impact of XR technology on the engagement of secondary school students in Biology?

The research was grounded in Kolb's Theory of Experiential Learning, a constructivist branch that suggests a four-step sequential learning process [14], [17]. Stanney et al. [19] assert that Extended Reality (XR) technology intensifies the iterative learning process involving experiential components such as self-managed practical exposure, multiple-viewpoint assessment, target definition for concept formation, and novel-context hypothesis verification. Through its immersive capabilities, XR technology induces introspective analysis, assists in situational interpretation, fosters connections with existing knowledge, and strengthens proactive participation in problem-solving and decision-making, promoting cognitive growth. Therefore, the congruence of this theoretical framework with the research design is evident, where XR technology is woven into Biology instruction. This allows learners to partake in immersive experiences characterized by abundant sensory, kinesthetic, auditory, and visual stimuli. The resultant effect is a decrease in cognitive burden and a bolstering of learners' intrinsic motivation, thereby fostering efficient learning [22], [32], [71], [72], [73].

This research employed a deductive method to derive indicators of cognitive, behavioral, emotional, and social engagement, as delineated in the studies by Cevikbas & Kaiser [12] and Cropanzano and Mitchell [48]. The findings of this research highlighted the sequence of student engagement in learning Biology via XR technology, with cognitive engagement taking precedence, followed by emotional, social, and eventually behavioral engagement. The derivation of these results was based on percentage ratio repetitions procured from MAXQDA software. Subsequently, these study outcomes are discussed in the context of prior literature, emphasizing the primary themes associated with engagement areas as determined by their frequency within the interview outcomes.

The research findings underscored the beneficial influence of XR technology across multiple facets of student engagement, cognitive, emotional, social, and behavioral, fostered through a technologically enhanced immersive environment. These outcomes find resonance in numerous studies [31], [32], [34], [35], [43], [74], [75], [76], [77]. Consequently, the ensuing discourse will concentrate on the sub-themes emerging from the four domains of engagement, buttressed by prior literature, revealing intriguing insights that contribute to a profound and contextual comprehension of student engagement.

The first identified theme (cognitive engagement) encompasses four sub-themes, namely, (learning perception, learning assessment, learning regulation, and learning application). Bond and Bedenlier [78] underlined the linkage of cognitive engagement to deep learning, which students then transform and retain post-learning sessions. The current research findings notably highlighted XR technology's effect on students' cognitive engagement. This was manifest in students' evaluative responses that embodied their learning perception sub-theme, as shown in the study by Joshi et al. [35]. Students exhibited self-monitoring and self-assessment in learning, error detection, and rectification under the sub-theme that pertains to their capacity to assess learning.

Moreover, their competency in regulating learning through information seeking and in applying learning by forming connections among learning subjects, recalling, and applying past learning, all signify the application of higher-order thinking skills, as highlighted in the study by Wallace-Spurgin [36]. The present research validated the effect of implementing experiential learning within an immersive technology-rich environment on boosting students' cognitive engagement by deeply incorporating higher-order thinking skills during the learning process. This is corroborated by Aguayo et al. [37], who indicated the amplified opportunities for learners to engage with virtual and augmented reality in an immersive environment, enhancing learning regulation and engagement. Katyara et al. [38] also affirm that integrating technology in learning facilitates information analysis, acceptance, or rejection of ideas and fosters autonomous participation, thereby augmenting learning regulation. This enhancement is achieved by deeply integrating higher-order cognitive skills during the learning process, reflecting Kolb's experiential learning theory [19].

The second discerned theme (emotional engagement) embodies three sub-themes, namely, (learning sufficiency, affection for learning, and learning motivation). The beneficial influence of XR technology on students' emotional engagement was distinctly observable in this research, as manifested by students' high levels of learning satisfaction and motivation, a finding supported by the studies of Llic et al. [73] and Tunur et al. [74]. Additionally, students displayed emotions associated with a passion for learning, such as interest, joy, enthusiasm, pleasure, zeal, and self-assurance [74]. It is also aligned with the concrete experience stage of Kolb's experiential learning theory. This stage, characterized by engaging in a new experience, stimulates various emotions, contributing to an emotionally rich learning experience [78]. The association between enjoyment and motivation in emotional engagement, leading to further cognitive and behavioral engagement, has been validated by studies such as those conducted by Iten and Petko [40] and Kluge et al. [41]. Bennett and Saunders' study [79] exhibited that a virtual learning environment amplifies the learning experience in biology, as demonstrated by students' pleasure and engagement in learning. The research also disclosed the impact of students' sense of learning responsibility, a component of motivation, in boosting emotional engagement during learning. This insight is backed by Marcus et al.'s study [42], which suggests that a heightened sense of responsibility toward their learning augments students' emotional engagement in learning. In contrast, the study unveiled a negative aspect associated with students' dissatisfaction with their use of VR glasses, which led to eye discomfort and failed to facilitate a practical and easy learning experience. This finding aligns with previous [80], [81] that highlight the adverse physical symptoms resulting from AR glasses use, including eye discomfort and neck pain, which negatively affected the practicality and ease of the learning experience.

The third identified theme (social engagement) incorporates two sub-themes (interaction and communication). Additionally, the research underscored a further finding that illuminates the function of interaction among learners and their peers and between learners and instructors in nurturing favorable emotional engagement. This was visible through the students' articulation of categories symbolizing social engagement while employing XR-based learning, enhancing their learning journey. The research findings spotlighted the effect of student interaction, their engagement in group dialogues, and cooperative tasks, corroborated by the research conducted by Garcia and Buskist [22]. The findings also underscore the communication between students and teachers, which indicates their social engagement. This encompasses seeking aid, assistance, feedback, and posing and responding to questions. These discoveries are validated by studies suggesting that structuring virtual learning in an academic setting that encourages peer engagement amplifies learning [7], [43], [82]. Further, the research by Mayordomo et al. [39] underscored the pivotal role of procuring feedback via asking questions within social engagement, which significantly impacts emotional engagement. This, sequentially, triggers positive emotions that augment cognitive engagement in learning.

The final theme identified in this research (behavioral engagement) incorporates two sub-themes (achievement and good classroom behavior). Additionally, the research unveiled the influence of implementing XR technology on students' behavioral engagement in their biology education. This was observable in the inferential category, symbolized by the ease of use, which was incorporated into the sub-theme of achievement. Learners conveyed the simplicity of using XR technology, particularly the three-dimensional display that enabled them to retrieve and scrutinize information merely by moving their hands. They articulated the straightforwardness of learning via this technology and their capacity to fulfill necessary tasks through self-reliance, active learning, and perseverance. These findings have been substantiated by numerous studies [32], [33], [38], [83]. Another intriguing discovery within the sphere of behavioral engagement was underscored in the sub-theme of good classroom behavior. Students communicated their adherence to classroom norms during learning and avoidance of negative behaviors. The observed improvement in classroom behavior supports the hypothesis posited by Katyara et al. [38] about the positive influence of technology on behavioral engagement by fostering beneficial peer relationships and encouraging respect for classroom norms during the learning process.

V. CONCLUSION

In this qualitative investigation, the researchers probed the effects of Extended Reality (XR) technology on engagement levels of high school students within Biology courses. Utilizing both deductive and inductive thematic analysis, our findings underscore that XR technology bolsters all four dimensions of engagement—namely, cognitive, emotional, social, and behavioral—with a significant emphasis on cognitive engagement. Notably, this research contributes to the theoretical literature by offering a distinctive application of the constructivist theory and Kolb's Experiential Learning Cycle within the ambit of XR technology use in Biology education. The nexus between established pedagogical frameworks and novel technological interventions advances our understanding of modern educational practices. Furthermore, this research novelty lies in its unique research context, focus on XR technology in Biology education and comprehensive approach to understanding student engagement.

However, certain limitations are evident. The constrained sample size potentially impacts the broader generalizability of our insights. While the research uniquely situates itself within the Biology discipline, the derived conclusions might not seamlessly extend to other academic spheres. The qualitative approach, grounded in thematic analysis, provides a rich tapestry of insights, but its outcomes may lack the breadth and general applicability typical of quantitative methodologies. Subsequent research initiatives would benefit from integrating larger and more diverse cohorts to fortify and expand the nuances of our findings. A broader exploration of the effects of XR technology on student engagement across varied academic disciplines is also merited. Furthermore, including a mixed-methods design in future investigations may achieve a harmonious blend of qualitative depth with quantitative breadth. This research augments the burgeoning literature on cutting-edge educational technologies and offers a fresh theoretical perspective, serving as a beacon for educators, curriculum designers, and policy framers in the ever-evolving educational landscape.

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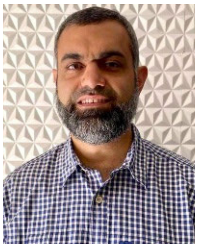

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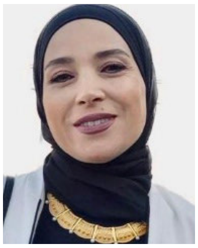

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