# Augmented Reality-Based Learning: The Efficacy on Learner's Motivation and Reflective Thinking

Kifaya Sabbah*, Fayez Mahamid, and Allam Mousa

***Abstract*—This paper describes a new experiment in the context of the Palestinian higher education based on Augmented Reality (AR) technology. The main objective is to investigate the efficacy of AR-based learning on motivation and reflective thinking, which are important measures of students' learning and achievement. The experiment was carried out on a sample of 24 students enrolled in digital communication course in their third and fourth years at telecommunication engineering department of An Najah National University. The sample was selected using purposive sampling method. Except for confidence dimension, results indicate a positive effect of integrating AR technology in teaching and learning on all dimensions of motivation (attention, relevance, satisfaction, and volition) between experiment and control groups. Similarly, AR-based learning has a positive effect on all dimensions of the reflective thinking scale between the experiment and control groups except for the reflection dimension. Furthermore, results indicate no significant differences between the experiment and control groups due to gender in favor of the experiment group. In contrast, there were significant differences between pre-test and post-test on motivation and reflective thinking scales and their dimensions in favor of the post-test. However, the research was limited by the small sample size and the novelty of the AR technology, which requires the instructors and students to be familiar with this emerging technology.**

***Index Terms*—Augmented reality, motivation, reflective thinking, AR-based learning**

## I. Introduction

Learners are expected to acquire the necessary professional and life skills and respond to society's demand for qualified graduates and global citizens [1]. Therefore, it is necessary to focus on teachers' practices and provide them with knowledge and skills for using emerging technologies in the educational context [2]. This enables them to design and develop educational activities and exploit the potential of these technologies for learning, teaching, and assessment in either face-to-face or online learning [3]. Researchers have customized the quality of services that learners receive based on process and structure factors. Process factors refer to the quality of interaction and engagement in the class, whereas structure factor refers to the resources that facilitate interaction [4]. This includes teachers' education, experience, and subject matter knowledge, as well as the availability of learning material and information and Communications Technology (ICT) infrastructure [5]. Moreover, the Horizon Report 2020 identified a significant impact of emerging technologies on education, one of which is extended Reality XR (Augmented Reality / Virtual Reality /Mixed Reality) haptic technologies [6]. Augmented Reality (AR) is a technology that overlays virtual objects onto the real world [7]. It is defined as "a situation in which a real-world context is dynamically overlaid with coherent location or context-sensitive virtual information" [8]. AR has been recognized as one of the technologies with a higher impact on university education [9].

Augmented reality was first developed in the 1960s by Sutherland [10]. Since the 1990s, AR technology has been used by some large companies for the visualization of their data and the training of their employees and researchers [8, 11]. It has been used in such fields as the military, medicine, engineering design, robotics, manufacturing, maintenance of applications, consumer design, and psychological treatment [12]. Although it has been used in other fields for a long time, AR has recently begun to show a good potential in educational settings. Bujak [13] mentioned, "AR is just starting to scratch the surface of educational applications."

Milgram *et al.* [14] analyzed the basic terms and concepts of AR as "augmenting natural feedback to the operator with simulated cues". The reality-virtuality continuum allows distinguishing between the concepts of virtual environment, also known as Virtual Reality (VR), and Augmented Virtuality (AV). It is a scale ranging from a completely real environment (reality), which can be observed when viewing the real world, to a completely virtual environment (virtuality). Within this continuum, the space between real and virtual environments is called mixed reality. Based on this continuum, mixed reality may be defined as a situation in which real and virtual objects are combined. While VR deals with settings where "the participant is totally immersed in a completely synthetic world", AR combines real and virtual worlds, supplementing the real world in real-time [15]. AR lies closer to the real environment end of the continuum, as shown in Fig. 1. AR is a combination of real and virtual objects and contains a small amount of virtual data, while AV is a concept where elements of reality are added to a virtual environment and contains more digital data [8, 16].

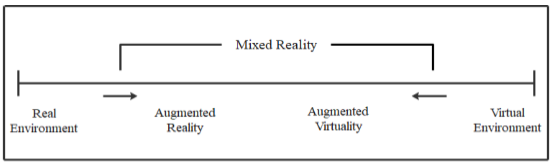


Fig. 1. Simplified Milgram's reality-virtuality continuum.

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Another accepted definition of AR is "a real-world context that is dynamically overlaid with coherent location or context_ sensitive virtual information" [17]. According to Azuma [18], AR has three key requirements: a) the combining of real and virtual objects in a real environment; b) a consistency between the real and virtual objects; and c) real-time interaction [15, 16, 19]. AR allows combining virtual content with the real world seamlessly [20]. In this sense, "AR supplements reality, rather than completely replacing it" [18]. Furthermore, Chung and Hsiao [21] mentioned that AR can be seen as a 3D visualization projected on physical surroundings, unlike VR, which is popularized by its full immersion in visual effects of the learning experience.

AR supports student-centered investigation and allows data collection and observation where fieldwork is not possible [22]. AR allows the visualization and manipulation of abstract phenomena, distant places, or those too dangerous to experience. It also allows communication with remote students or with subject experts, in addition to providing instant access to research data via the internet [23]. Azuma [18] conducted research to determine the advantages of AR and its features as a visualization tool for teaching science over traditional methods. Nevertheless, Kesim and Ozarslan [24] revealed that AR does not replace physical models. Instead, AR is a supplemental tool that provides an alternative way to show visual images to make abstract concepts more concrete and accessible to learners. He argued that with better learning infrastructure, technology can increase the reach of pedagogy by allowing teachers or instructors to teach more effectively, resulting in better learners' understanding and learning. For instance, Wu *et al.* [25] developed an animation to help learners understand the abstract concepts in Chemistry [26], and Stith [27] used software to create an animation of enzyme-substrate binding for teaching cell biology.

Furthermore, AR can assist teachers in updating teaching techniques to better support inclusionary education as well as enhance student motivation [28]. In addition to the importance of AR, it helps in developing student curiosity, observation, and experimentation [29]. AR technology is a way to combine playing and learning, in which learners develop their mental and cognitive abilities. It helps to develop learners' memories, thinking skills, imagination, and abilities [30]. Moreover, Badilla-Quintana [31] discussed the advantages of AR, which can improve the academic achievement of learners with and without special educational needs. Finally, using AR is effective in promoting deeper student engagement, perceived enjoyment, and positive attitudes [11].

Several researchers investigated motivation as an important psychology concept in education [3, 16, 32–34]. Most of them agreed that it is related to other educational concepts like curiosity, persistence, and performance [35]. Motivation is defined as the energy that drives students to learn and work hard on their school assignments [36] or students' desire to learn and engage in an educational environment [37]. It affects self-regulation and academic performance [38]. There are two types of motivation: Intrinsic Motivation (IM) that refers to engaging in a behavior that is satisfying or pleasurable in nature, and Extrinsic Motivation (EM) that arises from external action or socially creates a reason to do an action. IM is non-automated in nature: that is, a motive-driven action does not depend on any separate consequence action separated from the behavior itself. On the contrary, EM is instrumental in nature [39].

Keller [37] proposed a problem-solving approach to apply motivation in instructional design based on the Attention, Relevance, Confidence, and Satisfaction (ARCS) model [40]. The mentioned four categories influence learning and performance as a process or a model that consists of motivation, performance, and learning. ARCS is based on the macro theory of motivation and instructional design theory. It is grounded on expectancy-value theory, which considers that when a student performs activities that meet his personal needs, he will be motivated to engage with them [37]. This model explains how learners' attention or curiosity, their relevance or motives, are combined t with their confidence, or expectancy for success to assign the most valuable goals and make their best effort to achieve them. Environmental characteristics such as the availability of resources, teachers' eagerness, and social values affect directed goals. In addition, learners' skills and knowledge lead to performance. An individual's performance along with the way reinforcement contingencies are managed determine the consequences of achievement in relation to an expected outcome. These consequences, along with cognitive assessment and reflection determine levels of satisfaction with the process and the results. The dot lines present the feedback loops; one between effort and performance and another between performance and consequences. In addition, there is feedback from satisfaction, attention, and relevance that either weakens or strengthens the value associated with a specific goal. Finally, this model describes how internal environments and conditions effect behavior over time [36].

In the learning process, sometimes a learner has motivation, but he/she is confused or tiered, so he/she needs another factor to take action or convert intentions into actions, which is volition or self-regulation [37]. Volition is mainly based on different theories: Kuhl's theory of volitional control [41], Zimmerman's theory of self-regulatory learning [38], and Gollwitzer's theory of implementation intentions [42, 43]. Therefore, Keller [37] added a fifth factor (Volition) to the ARCS model to make it ARCS-V model. Keller [44] recently developed a reliable and valid scale to measure volition for learning in the context of the ARCS-V model in both online and face-to-face learning environments. With widely used the latest technology in learning environments the instructors and instructional designers should decide which technology effectively supports learners' motivation and reflective thinking activities [45]. Reflection plays an important role in the learning process, and it is very useful for enhancing learning performance [46] and for better understanding the learning content when learners reflect during the learning process [47]. There is no clear definition of reflection, and this makes it difficult to assess teacher practices and learners' learning [48]. Dewey [49] defined reflective thinking as "active, persistent, and careful consideration of any belief or supposed form of knowledge in the light of the grounds that support it and the further conclusion to which it tends". From

Dewey's writings on how to think, reflection is a meaning-making process to transfer the learner from one experience to the next with more understanding and by sharing the experiences with others. He should interact with others systematically and have a valued attitude toward intercultural development [48]. So, Dewey assumes that reflection includes a combination of attitudes and skills [50]. According to Boyd and Fales [51], reflective learning is the internal examination and exploration of an issue, triggered by an experience, creating and clarifying a meaning in terms of self, and resulting in changes in the conceptual perspective. Boud *et al.* [50] defined reflection as "an active process of exploration and discovery, which often leads to much-unexpected outcomes."

Different approaches involve reflection, such as journals, logs, and portfolios [52], but the most important issue is how to make learners reflect effectively. Some reflection skills assist learners in collaborative reflection through information sharing to evaluate others' ideas and improve the reflection effectively [53]. Kolb and Fry [54] argued that active learners need four kinds of abilities that match the four stages of his learning cycle, concrete experience, reflective observation, abstract conceptualization, and active experimentation. These stages form the concrete/abstract and the active/reflective dimensions of cognitive learning. According to Kolb, knowledge creation through the transformation of experience and learning cannot happen without reflection. In addition, Zimmerman [55] proposed three phases in his theory of self-regulated learning: forethought, performance or volitional control, and self-reflection. He divided self-reflection into four cyclical loops, self-evaluation, attributions, self-reactions, and adaptive behaviors. In addition, Montgomery suggested five steps for reflective learning, do, look, think, evaluate, and plan. In each step, learners reflect based on their performance in the previous step [56].

In 1983, Schön described reflective practice as an integration between thinking and doing and between thought and action, through which the learner becomes more skilled [57]. Furthermore, he divided the learners' reflection into three processes: reflection-for action, which means that reflection happens before the action: reflection-inaction, which means that reflection happens in the midst of the action: and reflection-on action, which means that reflection happens after the action [47, 53].

In this regard, Mezirow [58] developed a comprehensive, logical framework of reflective thinking that includes six levels of action: habitual, thoughtful, introspective actions, content, process, and premise reflections. According to Mezirow, premise reflection is a high level of reflective thinking similar to critical thinking, in which learners are aware what they think, feel, and perceive [59]. Reflection is also a metacognitive ability that concerns the observation and control of individual cognitive processes [47, 56]. Kember *et al.* [56] developed a reliable scale for reflective thinking based on literature, specifically the Mezirow framework, and consists of four levels: habitual action, understanding, reflection, and critical reflection [56].

However, several challenges were faced, such as implementation problems and social support, especially in e-learning and self-directed settings, where students are not actively engaged with instructors and other students. Implementation problems can result from poorly designed materials that lack well-written text and adequate visual elements [33]. Challenges include managing the learning and motivational components of the learning environment, especially with regard to integrating technology and innovative delivery systems. Nevertheless, integrating the ARCS-V model with instructional design can lead to instructionally rich and motivating learning activities that are appropriate for a given setting [33]. Such cases prompt the adoption of AR technology into education for interactive learning involving student engagement to improve their motivation towards learning [60]. To the researcher's knowledge, the ARCS-V model has not yet been used in AR-based research. In addition, a few researchers have measured the influence of AR-based learning on students' reflective thinking [15]. Therefore, this research will add a new and important contribution to the mentioned aspects and relevant domains and variables.

The 21st-century skills include a range of competencies, such as critical thinking, problem solving, creativity, meta-cognition, communication, digital literacy, civic responsibility, and global awareness [61]. These competencies are important for developing countries, where improving the learning outcomes and the instructional quality is urgent. Unfortunately, these countries lack a context-specific understanding of teaching practices as well as meaningful ways of supporting teachers' professional development [62].

The above drawbacks in the educational system should be resolved to improve the educational process in a methodological, technical, and pedagogical direction in accordance with modern realities [63]. For instance, it is necessary to conduct specialized professional development programs to improve the knowledge and proficiency of instructors in order to enable modern learners to focus on global trends when addressing issues of innovation in the educational process.

Fortunately, An-Najah National University is currently implementing a project that aims at enhancing education with XR. The researchers will intervene on a subset of students enrolled in an AR-based Telecom engineering course. In this discipline, AR has several functionalities that can support the needs of perception or technical representations in teaching.

The current research will be the first to investigate the integration of AR into teaching and learning among university students in Palestine. Utilization of AR for enhancing learner motivation improves course material visualization for better understanding. This research contributes to identifying the efficacy of AR-based learning on motivation and reflective thinking of a sample of students enrolled in Telecom Engineering AR-based classes.

In this research, the researchers will answer the following main questions:

1) Are there differences in learners' motivation dimensions between experimental and control groups on pre- and post-tests?
2) Are there differences in learners' reflective thinking dimensions between experimental and control groups on

pre- and post-tests?
3) Are there significant differences in motivation between pre-test and post-test for the experimental group (students who received the AR intervention)?
4) Are there significant differences in reflective thinking between pre-test and post-test for the experimental group (students who received the AR intervention)?
5) Is there any significant relationship between motivation and reflective thinking for the students in the digital communication course?

## II. METHODOLOGY

### A. The Sample

The sample consists of 24 students in the telecom engineering department who enrolled in a digital communication course during the second semester of the academic year 2021–2022 at An-Najah National University using the EON-XR platform for AR-based learning. This sample was selected using the purposive sampling method, which enabled the researchers to use their special knowledge or expertise about the sample's proficiency with AR as a phenomenon of interest. The students who participated in the experiment are in grades 3 and 4, with ages ranging from 20 to 21. The sample is divided equally between the experimental and control groups, and between males and females as well. The socioeconomic status of the sample is moderate for 66.7%, very good for 30.6%, and low for 2.8%. All of the students have smartphones and laptops. Their ICT skills are good for 36.1%, moderate for 55.6%, and low for 8.3%.

### B. Instruments

The researchers used the Reflective Thinking Scale (RTS) and motivation (ARCS-V) scales, where ARCS and Volition for Learning Scale (VFLS) were combined into one scale, as described below:

1) Reflective Thinking Scale (RTS): Keller [56] created this scale to assess the level of reflective thinking required to conduct the proposed research. The scale consists of four dimensions: (1) habitual action, (2) understanding, (3) reflection, and (4) critical reflection with 16 items. These items feature a five-point Likert response scale (1 = not true; 5 = very true).
2) Motivation Scale: The Instructional Materials Motivation Survey (IMMS) has been developed by [64]. This research employed the ARCS model for motivation based on. Pre- and post-usage questionnaires to compare student learning motivation and to determine if there was a statistically significant difference in motivation, The IMMS survey comprises 12 items to measure Attention, nine items to measure Relevance, nine items to measure Confidence and six items to measure Satisfaction. IMMS was chosen based on its successful use in previous studies to determine the influence of AR technology on student motivation [16, 60].
3) Volition for Learning Scale (VFLS) developed recently by Keller [44] consists of 13 items. The fifth component, Volition was added to the ARCS model. The instrument is valid and reliable, and it has been successfully used in the context of motivation modeling, as demonstrated by Keller [44] results. The scale was comprised of two factors: action planning with five items and action control with eight items.

Person correlation coefficients between the four dimensions of reflective thinking range between 0.508 and 0.757, and between 0.487 and 0.901 for motivation scale (ARCS-V), which are acceptable [65]. Moreover, Cronbach's alpha was used to test the scales' reliability: with a total of 0.749 for reflective thinking, which is acceptable according to Straub [66], and a total of 0.901 for motivation, which is acceptable according to Nunnally and Bernstein [67], Finally, the Guttman Split-Half Coefficient was calculated to be 0.657 for reflective thinking and 0.864 for motivation in the split-half reliability analysis.

### C. Experiment

The researchers conducted the experiment on the digital communication compulsory course in the telecommunication engineering program, which was accredited by Accreditation Board for Engineering and Technology (ABET) in 2014. Currently, the digital communication course is being evaluated again for the second cycle. Hence, the course syllabus, assessment criteria, course objectives, and outcomes are all being assessed, and feedback is being provided. The course prerequisites are communication principles and electromagnetics 2.

The researchers followed the five stages of the Analyze, Design, Develop, Implement, and Evaluate (ADDIE) model [68] to conduct the experiment:

#### 1) Analyze

This is the first phase, which is essential to developing the next phases, which include analysis of learning goals and the content of the course material. In addition, it identifies the targeted students' characteristics and the learning environment.

- Analyze the learning goals: the extent to which the learning goals are achieved when integrating augmented reality into the learning process.
- Analyze the content of the course material, including the course description and learning outcomes, as follows:

This course covers digital communication concepts including sampling, quantization, pulse code modulation, Time Division Multiplexing (TDM), digital multiplexer, and quantization noise in Pulse Code Modulation (PCM) systems. In addition, it covers delta-sigma modulation, linear predictive coding, differential pulse code modulation, and baseband digital transmission and communication model, a matched filter, error rates due to noise detection of baseband signals in Additive White Gaussian Noise (AWGN), and Inter-Symbol Interference (ISI). Moreover, it discusses Nyquist criteria for distortionless channels, M-ary baseband transmission, correlative level coding, a passband digital transmission model, coherent phase shift keying, M-ary phase-shift keying (QPSK and M-ary PSK), hybrid amplitude/phase modulation schemes (M-ary-QAM), coherent frequency-shift keying, noncoherent orthogonal modulation, noncoherent binary FSK, differential phase-shift keying, M-ary FSK, effects of noise on various modulation schemes, and average probability of error versus increased bandwidth transmission. Learning outcomes are:

- Ability to apply knowledge of mathematics, science, and engineering to study noise effect, average probability of error, and spectral efficiency of baseband and passband communication systems.
- Ability to design a digital communication system that meets spectral efficiency, noise effect, and average probability of error.
- Ability to use the techniques, skills, and modern engineering tools necessary for engineering practice (i.e., course project).
- Identify the learning environment: this includes a description of the learning environment, including the learning enticement and the educational issues if any. The learning environment is based on face-to-face lectures that are delivered in a classroom or a computer laboratory that is provided. The classrooms are facilitated with projectors and Internet service. Moreover, the learning-assessment activities are designed and implemented by the lecturers.

*2) Design*

- Design a scale for the pre-test and post-test.
- Identify lesson objectives: Students should be able to: Convert an analog signal into a digital signal and vice versa (Assignment 1), identify the multiplexing technique in the time domain and the E1 system (Assignment 2), discuss the concept of a matched filter and its applications in communication systems (Assignment 3), discuss the concepts of Inter-Symbol Interference (ISI) and the Additive White Gaussian Noise (AWGN) in communication systems (Assignment 4).
- Describe learning style for the learners: Groups work on projects and learn by doing. Each group consists of 2–3 students who work on XR activities and XR presentations.
- Identify the educational resources (images, video, audio, assessment): During the class, the instructor uses the textbook, PowerPoint slides, and lecture notes. In addition, he provides students with self-learning material on Moodle, such as links, videos, and recorded lectures. The XR activity includes videos, images, 3D recordings, audio recordings, assignments, and exams.
- Identify the learning strategy: The students rely on learning by doing, cooperative learning, and presentation skills.

*3) Develop*

In this stage, the educational resources are developed using the EON-XR platform through several assignments to the targeted students. The instructor's role is to create accounts for the students on the EON-XR platform and provide them with training on developing learning objects and uploading digital resources such as images, audio, and video clips. The student's role is to develop AR-based learning models as assignments and projects to evaluate the learning progress.

*4) Implement: Integration of AR into learning*

The instructor assigned four learning activities to the targeted students with clear goals that covered the content to extend students' learning rather than test their existing knowledge. These assignments are:

- Assignment 1 (Project): Students must complete a detailed project on A/D and D/A conversion using both hardware and software.
- Assignment 2 (Project): Students need to develop the concept of Time Division Multiplexing (TDM) system in general, then they need to discuss the E1 system.
- Assignment 3: Students need to discuss the concept of a Matched Filter and its applications in a communication system.
- Assignment 4 (Project): Students need to discuss the concepts of Inter-Symbol Interference (ISI) and the Additive White Gaussian Noise (AWGN) in a communication system.

*5) Evaluate*

Using XR projects and midterm and final exams. For the projects, each group should develop one 3D lesson satisfying at least one of the evaluation criteria (annotations or labels, memos with audio narrations, videos, 3D recordings, activities with locate and identify, images, PDFs, and quizzes "change default answers"). Fig. 2 shows a sample AR-based 3D model developed by the students.

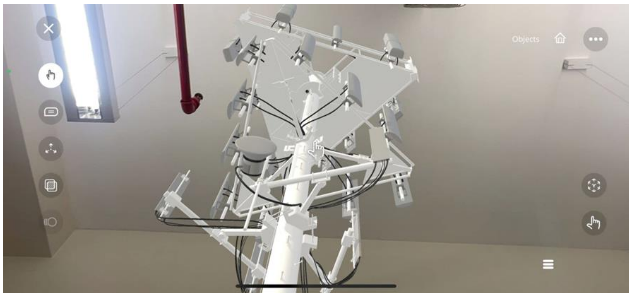

Fig. 2. A sample AR-based 3D model developed by the students.

VR and AR and developing their models and lessons in the AR-based learning experiment for the data communication course. They used the EON-XR platform for developing their 3D-models, instrumented with Oculus to immerse with their models interactively.

## *D. Research Procedures*

Both motivation and reflective thinking scales translated from English into Arabic and were reviewed by five Arab arbitrators who have experience in psychology, Arabic, and education. They reviewed the clarity and comprehensiveness of the scales to ensure content validity.

Accordingly, the researchers made minor modifications based on the feedback of the arbitrators. After completion, the scales' translated draft was back-translated into English by an independent translator, according to the guidelines developed by Sousa and Rojjanasrirat [69]. To examine scales' validity and reliability, 77 undergraduate students at the An Najah National University (i.e., pilot testing sample) independent from the study sample were asked to answer the Arabic-translated version of the scales to validate them in the Palestinian context. Participants were provided with descriptions of the scales and the purpose of the research, and those who agreed to participate in the research. In addition, factor exploratory and confirmatory analyses were performed to develop the final versions of the both motivation and reflective thinking scales. The final version of the scales was distributed to the study sample for data collection and further data analysis.

### *E. Data Analysis*

Descriptive statistics were calculated to test the statistical reliability of the instruments and study variables included in the research design. In order to evaluate the psychometric properties of ARCS-V and RT, we assessed: content validity (content validity index), internal consistency (Cronbach's alpha), theoretical relevance (exploratory and confirmative factor analysis) and Pearson correlation analysis was conducted to assess the associations among the variables. The researchers also used Paired samples t-test to calculate the differences between pre-/post-test among experimental and control groups.

## III. Results

The sample size for the Digital Communication course was less than 50. Therefore, we used the Shapiro-Wilk test to investigate the normality assumption because it is more appropriate for small sample sizes (<50 participants) [70]. The normality assumption was satisfied as the significance was more than 0.05. For motivation scale, the significance was ($p = 0.533$) for the pretest and ($p = 0.414$) for post-test. In addition, the significance for the reflective thinking scale was ($p = 0.11$) for the pre-test and ($p = 0.538$) for the post-test. Therefore, we used parametric tests in our analysis.

Results related to the question 1:

Are there differences in learners' motivation dimensions between experimental and control groups on pre- and post-tests?

To answer this question, the researchers started with the independent t-test to examine the statistical differences in the student's motivation pre-test due to gender and group (Pre-treatment Measure of Equivalence). There were no significant differences ($p = 0.05$) between the experiment and control groups, according to the t-test results for independent groups (t-value = −2.280, $p = 0.334$. Similarly, the result shows no significant differences between males and females (t-value = 1.331, $p = 0.442$). This result indicates that the previous motivation level of both genders and groups is equal, which means they are suitable for the study. Results of Table I show apparent differences between means on the total score of the motivation scale and all its dimensions due to group and gender in favor of the post-test.

After that, the researchers used the one-way analysis of co-variance (ANCOVA) test to determine statistically significant differences between groups on post-test scores, controlling for pre-test scores. Before the test, the researchers examined the assumption of homogeneity of regression, where no violation was found ($F = 4.196808$, $p > 0.05$). Results of the ANCOVA test are depicted in Table I.

Results from Table 1 show significant differences between the experimental and control groups on the total score of the motivation scale, favoring the experimental group. In contrast, results show no significant differences due to gender, pre-test, and interaction between group and gender.

TABLE I: Analysis of Covariance for Total Score of the Motivation Scale Due to Group and Gender

| | Source | Sum Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| Motivation | Total Pre-test | 0.547 | 1 | 0.547 | 4.589 | 0.045 |
| | Group | 1.468 | 1 | 1.468 | 12.322 | 0.002 |
| | Gender | 0.018 | 1 | 0.018 | 0.149 | 0.704 |
| | Group * Gender | 0.139 | 1 | 0.139 | 1.169 | 0.293 |
| | Error | 2.264 | 19 | | | |
| | Total | 299.373 | 24 | 0.119 | | |

In order to test the significance of these differences on the motivation dimensions, multiple analysis of covariance (MANCOVA) was employed, as shown in Table II.

TABLE II: Multiple Analysis of Covariance for the Motivation Dimensions Due to Groups and Gender

| Dependent Variable | Source | Sum Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| Attention | Group | 0.728 | 1 | 0.728 | 4.573 | 0.046 |
| Relevance | | 1.125 | 1 | 1.125 | 9.240 | 0.007 |
| Confidence | | 0.776 | 1 | 0.776 | 3.246 | 0.087 |
| Satisfaction | | 2.242 | 1 | 2.242 | 9.732 | 0.006 |
| Volition | | 1.977 | 1 | 1.977 | 7.286 | 0.014 |

Results related to the question 2:

Are there differences in learners' reflective thinking dimensions between experimental and control groups on pre- and post-tests?

To answer this question, the researchers first used an independent t-test to examine the statistical differences in the student's reflective thinking pre-test due to gender and group (Pre-treatment Measure of Equivalence), Results show no significant differences between the experimental and control groups (t-value = −0.195, $p = 0.587$). Similarly, results show no significant differences ($p <= 0.05$) between male and female students (t-value = 1.316, $p = 0.94$). This indicates that the previous level of reflective thinking level due to gender and group is equivalent, which means they are suitable for the study. After that, the researchers calculated the means, standard deviations, and medians for the experimental groups on the pre-test and post-test for the reflective thinking scale. The results in Table III show apparent differences between the means on the total score of reflective thinking and all its dimensions due to gender and group in favor of the post-test.

In order to examine the significant differences between groups on post-test scores after controlling for pre-test scores, and after examining the assumption of homogeneity of regression with no violation (F = 2.467, p > 0.05), the researchers conducted a one-way analysis of co-variance (ANCOVA), as shown in Table III.

TABLE III: ANALYSIS OF COVARIANCE FOR TOTAL SCORE OF REFLECTIVE THINKING SCALE DUE TO GROUP AND GENDER

| Dependent Variable | Source | Sum Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| Reflective Thinking | Total _Pretest | 0.001 | 1 | 0.001 | 0.008 | 0.931 |
| | Group | 1.459 | 1 | 1.459 | 19.958 | 0.000 |
| | Gender | 0.195 | 1 | 0.195 | 2.674 | 0.118 |
| | Group * Gender | 0.217 | 1 | 0.217 | 2.973 | 0.101 |
| | Error | 1.389 | 19 | 0.073 | | |
| | Total | 377.211 | 24 | | | |

Results of Table III show significant differences between the experimental and control groups on the total score of the reflective thinking scale, favoring the experimental group. In contrast, results indicate no significant differences due to gender, pre-test, and interaction between group and gender. In the last step, and to examine the significance of these differences on the reflective thinking dimensions, a Multiple Analysis of Covariance (MANCOVA) was used, as shown in Table IV.

TABLE IV: MULTIPLE ANALYSIS OF COVARIANCE FOR REFLECTIVE THINKING DIMENSIONS DUE TO GROUP AND GENDER

| Dependent Variable | Source | Sum Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| Habitual Action | Group | 1.459 | 1 | 1.459 | 19.958 | 0.000 |
| Understanding | | 2.474 | 1 | 2.474 | 16.270 | 0.001 |
| Reflection | | 0.694 | 1 | 0.694 | 2.352 | 0.142 |
| Critical Reflection | | 1.336 | 1 | 1.336 | 8.235 | 0.010 |

Results of Table IV show significant differences between experimental and control groups on reflective thinking dimensions in favor of the experimental group except for Reflection. In contrast, results show no significant differences due to gender, pre-test, and interaction between group and gender on reflective thinking dimensions.

Results related to the question 3:

Are there significant differences in motivation between pre-test and post-test for students who received the AR intervention?

To find the differences between pre-test and post-test on the experimental group, the researchers calculated the means, standard deviations, and paired samples a t-test was conducted to test the differences between pre-test and post-test for the experimental group on motivation and its dimensions, as shown in Table V.

TABLE V: MEANS, STANDARD DEVIATIONS AND PAIRED SAMPLES T-TEST FOR MOTIVATION SCALE AND ITS DIMENSION

| Dimension | Test | Mean | S. D | T-value | df | Sig |
|---|---|---|---|---|---|---|
| Attention | Post-Test | 3.7083 | 0.44735 | −3.142 | 11 | 0.009 |
| | Pre-Test | 3.3264 | 0.26699 | | | |
| Relevance | Post-Test | 4.0093 | 0.33986 | −3.928 | 11 | 0.002 |
| | Pre-Test | 3.3796 | 0.47011 | | | |
| Confidence | Post-Test | 3.7593 | 0.48277 | −2.517 | 11 | 0.029 |
| | Pre-Test | 3.2870 | 0.43022 | | | |
| Satisfaction | Post-Test | 3.9861 | 0.49979 | −4.120 | 11 | 0.002 |
| | Pre-Test | 3.1806 | 0.63746 | | | |
| Volition | Post-Test | 3.7639 | 0.44215 | −3.540 | 11 | 0.005 |
| | Pre-Test | 3.2222 | 0.38817 | | | |
| Total | Post-Test | 3.8229 | 0.35417 | −4.346 | 11 | 0.001 |
| | Pre-Test | 3.2847 | 0.33231 | | | |

Results of Table V show significant differences between pre-test and post-test on motivation in favor of the post-test, where the means of the post-test and pre-test are (3.8229, 3.2847) respectively.

Results related to the question 4:

Are there significant differences in reflective thinking between pre-test and post-test for students who received the AR intervention?

To find the differences between pre-test and post-test among the experimental group, the researchers calculated the means, standard deviations, and the paired samples t-test was conducted to examine the differences for reflective thinking and its dimensions between pre-test and post-test for the experimental group, as shown in Table VI.

Results show significant differences between pre-test and post-test on reflective thinking in favor of the post-test, where the means of the post-test and the pre-test are (4.1823, 3.1667) respectively.

TABLE VI: MEANS, STANDARD DEVIATIONS AND PAIRED SAMPLES T-TEST FOR REFLECTIVE THINKING SCALE AND ITS DIMENSION

| Dimension | Test | Mean | S. D | T-value | df | Sig |
|---|---|---|---|---|---|---|
| Habitual Action | Post-Test | 3.9792 | 0.37626 | −8.110 | 11 | 0.000 |
| | Pre-Test | 2.9167 | 0.40358 | | | |
| Understanding | Post-Test | 4.4167 | 0.24618 | −9.043 | 11 | 0.000 |
| | Pre-Test | 3.3958 | 0.24905 | | | |
| Reflection | Post-Test | 4.0833 | 0.62462 | −3.458 | 11 | 0.005 |
| | Pre-Test | 3.3125 | 0.47822 | | | |
| Critical Reflection | Post-Test | 4.2500 | 0.36927 | −9.570 | 11 | 0.000 |
| | Pre-Test | 3.0417 | 0.39648 | | | |
| Total | Post-Test | 4.1823 | 0.27754 | −10.921 | 11 | 0.000 |
| | Pre-Test | 3.1667 | 0.28620 | | | |

Results related to the question 5:

Is there any significant relationship between motivation and reflective thinking for students who received the AR intervention?

In order to answer this question, the researchers computed the Pearson Product Moment Correlation Coefficient to investigate any significant relationship between the independent variable (reflective thinking) and the dependent variable (motivation) for the students of the digital communication course, as shown in Table VII.

TABLE VII: PEARSON PRODUCT MOMENT CORRELATION COEFFICIENT TO INVESTIGATE THE RELATIONSHIP BETWEEN MOTIVATION AND REFLECTIVE THINKING

| Reflective Thinking | | Motivation | | r | Sig |
|---|---|---|---|---|---|
| Mean | S. D | Mean | S. D | | |
| 4.1823 | 0.27754 | 3.8229 | .35417 | 0.619* | 0.032 |

*$p < 0.05$

Results of Table VII show a significant positive correlation at the 0.05 level (r = 0.619, p < =0.032) between motivation and reflective thinking. The regression analysis for predicting motivation is shown in Table VIII.

TABLE VIII: LINEAR REGRESSION TO PREDICT MOTIVATION

| Predictor | B | S. E | β | T | P |
|---|---|---|---|---|---|
| Reflective Thinking | 0.500 | 0.201 | 0.619 | 2.492 | 0.03* |

*$p < 0.05$

Table VIII found that reflective thinking contributed in a way that was statistically significant toward explaining 38.3 % of variance in motivation (B = 0.500, SE = 0.201, β = 0.619).

## IV. DISCUSSION

Results showed that AR-based learning activities affect all motivation dimensions except confidence, such as attention, relevance, satisfaction, and volition. This is because learners should build confidence by feeling in control and expectancy for success. For instance, unconfident people fear anything new and are worried about failure. In this case, it will be the teacher's responsibility to support students' self-confidence, show them different examples, and re-design the course or tasks if they are not comfortable for them [71]. Results suggest that AR technology does not foster higher levels of confidence than the control group. Therefore, further research is necessary to identify the students' sense of control while using AR in learning and to measure their perceptions of success in performing AR-based learning activities. This helps to overcome this obstacle and achieve a better level of confidence. Our results match Khan's regarding motivation in both attention and satisfaction dimensions but contravene with relevance and confidence dimensions [16].

In addition, results indicate no significant differences due to gender in the motivation for the course using AR technology. This result is considered logical, since the students live in similar circumstances and are supposed to be digitally literate with similar ICT skills, indicating a narrowing of the gender digital gap as some studies suggest [72]. Other studies indicated enhanced learning motivation in digital contexts, which made the content meaningful and relevant for both genders.

In general, our results agree with Moreno-Guerrero's [73] results, which indicated that all of the motivation dimensions had a very high and significant relationship. They concluded that AR was effective in teaching high school students physical education, especially for the acquisition of spatial-oriented content.

In addition, AR-based educational methods take into account the individual differences among the students and thus increase the students' self-confidence as each student proceeds in the educational process according to his ability, desire, and speed. Therefore, students could learn without fear, which positively affected the development of motivation among them.

Furthermore, results show that AR methods simplify complicated and abstract concepts, which has an impact on motivation. This can be attributed to the diversity of activities and teaching methods, since the difficulty of the topics assigned to the students reduces his motivation, as stated by Alhanai and Almanthari [74]. This result can also be justified by the fact that AR-based methods improve the students' engagement in the lessons and increase their educational interaction, which allows for better understanding. This agrees with Ivanova & Ivanov [75] who reported a positive impact of AR technology on the development of students' motivation.

According to the research findings, the AR applications and activities developed for the digital communication course were extremely enjoyable, motivating, and intriguing to affect student success. In addition, a positive correlation of 0.619 was found between motivation and reflective thinking, which agrees with previous studies like [76, 77]. Quantitative research with a correlation coefficient of 0.931. This result indicates evidence of a strong relationship between the research variables of our study. It supports the researcher's suggestion that reflective thinking assists students to reflect on their practices, activities, and lessons, which improves their self-efficacy and motivation. This result matches the previous research [78], which can be attributed to the fact that the learning outcomes are reflections of students' abilities, such as cognitive abilities, which cover six domains: knowledge, understanding, application, analysis, synthesis, and evaluation. Moreover, reflection helps the alumni students to focus on being motivated to continue innovation while identifying their career path. Clarke [79] reported that the reflective thinking model represents an excellent reflection tool to detect improvement opportunities and an effective method to learn from others' experience.

Our findings show that the experimental groups' reflective thinking supplemented with AR applications is significantly higher in all dimensions, including habitual action, understanding, reflection and critical reflection in the digital communication course. The researchers explained the result: a student begins to design an AR model many times and to solve the related activity without difficulty (i.e., a habitual action activity). This lets him understand the concept in a better way (i.e., understanding activity), think about his work (i.e., reflection activity), and then try to make it better in a different way the second time (i.e., critical thinking activity). Our results in this regard conform to [15, 80], which point to positive views toward AR applications in education, where the AR group achieved higher scores.

Our findings show that the reflection dimension was not significant, since reflection appears when exploring action reasons or assumptions that usually occur but rarely are observed [56]. In addition, reflection may affect students' affective levels rather than cognitive levels. In order to improve the students' reflection, the researchers suggest that students should be provided with training on writing reflections. Moreover, reflection should be implemented in a structured and intentional manner throughout the students' academic careers to improve their academic performance [76]. In this study, the experimental groups' reflective thinking supplemented with AR was significantly higher than the control group Even though both groups' skills improved after implementing reflective learning activities, AR-based learning had a greater impact on reflective thinking. Tok [46] supports our findings that reflective thinking has a positive impact on the students' performance.

However, this research has some limitations that should be addressed later in future research. The sample size is relatively small. In addition, the experiment focused on one course in telecom engineering and needs to be implemented in other subject areas. In addition, practicing AR-based learning was based on one 16-week semester, which is too short to get accurate results that could be generalized. Moreover, AR applications and models require considerable resources and special training for students and instructors that cannot be adequately provided within one semester. As for the study instruments based on (ARCS-V) motivation and reflective thinking scales, they need to be tested more frequently in the Palestinian education context on AR-based courses. Furthermore, the novelty of the Augmented and Virtual Reality Center at An-Najah National University, where AR is employed in teaching and learning for the first time in the semester of our experiment, accordingly, the participants expressed that the implementation of AR needs experience, training, and evaluation for the next experiments.

## V. Conclusion

This research makes a new contribution to the field of teaching and learning. It investigates two important factors that affect students' learning and instructors' teaching methods, motivation and reflective thinking, while implementing a new experience in education with an emerging technology for both students and instructors. This technology shapes the future of several aspects of the metaverse, namely in education, which is Augmented Reality (AR). This section provides a summary of our main findings following an intensive work with students and instructors practicing AR in learning and teaching an engineering course using the EON-XR platform. This study found that AR-based learning improves student motivation by allowing students to communicate with one another more effectively. It enables learners to develop their motivation via appropriate feedback, sharing AR projects, exchange of experience, time and place flexibility, and discussion among students and their instructor. The AR-based methods improve engagement in the lessons and increase their educational interaction for better understanding. Furthermore, AR applications and activities make learning extremely enjoyable, motivating, and intriguing to affect student success. In addition, AR-based educational methods consider the individual differences among the students, where each student learns without fear according to his ability, desire, and speed. Moreover, AR videos assist instructors in explaining the complex concepts being taught and enable students to memorize them. The Design of AR models and related student-driven activities enhance students' learning and, engagement and therefore, perform better on their assignments and exams. They acquire more skills that enable them to align what they have learned with life skills.

Since AR is an emerging technology, Palestinian education system could benefit from its advantages by integrating AR into the learning process in the Palestinian schools and universities. Accordingly, the researchers suggest that the curricula in the Palestinian HEIs should be supported with AR in science, technology, and engineering courses in the first phase, as these courses are plentiful with complex concepts that require imagination skills. In the next phases, this experience can be gradually transferred to other courses in different disciplines.

In order to succeed in this initiative, essential training programs should be developed and delivered for teachers and supervisors to design their courses and lessons based on both AR and VR applications. Also, it is suggested that teachers optimize the existing features according to the available ICT infrastructure to better facilitate students learning. Moreover, networking with peer institutions in other countries is necessary to work on joint projects that provide the necessary equipment and requirements to implement this technology, like applications, technical equipment, tutorials, and training, and exchange of experience and best practices. This initiative should be led by developing educational policies and strategies towards integrating AR into education.

This will increase the opportunities for students to be highly motivated and equipped with reflective thinking skills in their learning and lifelong practices.

As the results show, AR technology does not foster higher levels of confidence. Therefore, further research will be conducted to identify the students' sense of control while using AR in learning and to measure their perceptions of success in performing AR-based learning activities. This helps to achieve better level of confidence. Moreover, some previous studies show that enhancing achievement motivation in the digital context makes the content meaningful and relevant for both genders. So, further research will be done to investigate the importance of interaction with AR in learning different disciplines.

## Conflict of Interest

The authors declare no conflict of interest.

## Author Contributions

Kifaya Sabbah conducted the research, analyzed the data, and drafted the paper; Fayez Mahamid has provided the review and the discussion of the educational aspects of the study while Allam Mousa has provided the review, the facilitation of the AR-related experiences, and the discussion of the technical activities. All authors had approved the final version.

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