

# Comparing the effectiveness of video and stereoscopic 360° virtual reality-supported instruction in high school biology courses

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## Abstract

The promise of using immersive technologies in learning has increasingly been attracting researchers' and practitioners' attention. However, relevant empirical works are usually conducted in fully controlled Virtual Reality (VR) laboratories, as opposed to conventional settings. This quasi-experimental study compares the effectiveness of video learning resources to that of stereoscopic 360° VR, as supplements to the traditional instructional approach. The potential of such methods was examined in high school settings, in the context of the 'Life and Evolution' module, with participants ( $n = 70$ ) divided equally into control and experimental groups. As a point of reference (control condition), we considered the adoption of Video Learning Resources, as students are more acquainted with this instructional method. In the intervention approach (experimental condition), students adopted the use of low-end mobile-VR (*VeeR Mini VR Goggles*). The key findings indicate differences in the learning motivation, confidence and satisfaction, but no statistically significant difference was identified regarding the factual or conceptual knowledge gains. The study offers insights on the potential of the investigated technologies in the subject of secondary school Biology and further provides implications for theory and practice.

## KEYWORDS

academic achievement, molecular biology, motivation, multimedia, secondary education, stereoscopic 360° virtual reality, video

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## Practitioner notes

What is already known about this topic

- Researchers' interest over the potential of Virtual Reality on different STEM disciplines is increasing consistently.
- An increasing number of efforts can be identified discussing the integration of multimedia learning resources in the secondary school context.
- Empirical studies on the subject of Biology are focusing on students' academic performance and achievement but not on learning motivation and satisfaction.

What this paper adds

- This quasi-experimental study comparatively examines academic performance, with the focus being on learning motivation and satisfaction, across different modalities (stereoscopic 360° Virtual Reality applications-VR, Video Learning Recourses-VLR).
- The findings demonstrate that both instructional methods are sufficient in enhancing students' knowledge acquisition and academic performance.
- The adoption of stereoscopic 360° VR influences students' learning motivation and impacts long-term memory retention.

Implications for practice and policy

- Educators are advised to consider the systematic adoption of “immersive” multimedia tools to enhance the subject of Biology as they can greatly encourage scientific inquiry.
- Instructional designers are advised to adopt open educational resources aligned to the curriculum of the local context.
- Educational researchers are advised to integrate stereoscopic 360°-VR solutions in the conventional classroom settings.

## INTRODUCTION

Biology is arguably one of the most difficult core science subjects to both teach and grasp. Researchers (Green et al., 2018; Walker, 2021) attribute this to the limited opportunities learners have for experimentation in laboratory settings. Others (Hodges et al., 2021; Uz-Bilgin & Thompson, 2021) underline the negative impact that this inadequacy has in narrowing the theory–practice gap which, naturally, translates to decreased learning motivation, interest and knowledge growth. Things get worse when it comes to subjects like Molecular Biology (MB), as learners struggle to understand the fundamental concepts that govern the structure (composition) of cellular molecules or the underlying processes when they interact with other elements.

Computer-supported instruction can significantly mitigate these shortcomings so long as the integration of technology is systematic and the utilisation is regular (Christopoulos & Sprangers, 2021). Nevertheless, there are scholars (Blikstein et al., 2016; Monkovic et al., 2021; Wang et al., 2019) who argue against the adoption of general-purpose digital tools—especially for such complex subjects—characterising them as ineffective in providing authentic learning experiences. Furthermore, lecture-based curriculum, even when supported with digital learning tools, has been reported as ineffective in cultivating learners' foundational knowledge and understanding (Heddy & Sinatra, 2013; Lei et al., 2015; Marsteller & Bodzin, 2015).

Previous systematic reviews (Pellas et al., 2021; Pirker & Dengel, 2021) have concluded that the integration of multimedia elements into the instructional process can bring additional

benefits that the traditional approaches lack. To date, various digitally supported instructional methods have been proposed for the enhancement of MB courses, including simulation videos (Musaeus & Musaeus, 2021), interactive storytelling videos (Goodsell et al., 2021) and utilisation of 3D-printed models coupled with instructional videos (Monkovic et al., 2021). In the same vein, there is a common conviction across educational researchers (Hodges et al., 2021; Morimoto & Ponton, 2021; Uz-Bilgin & Thompson, 2021) that immersive technologies can provide multiple benefits on both academic performance (knowledge acquisition and advancement) and psychological adjustment (motivation, engagement) which are, collectively, conducive to long-term memory retention (Gomes et al., 2019). These conclusions are also in line with the recommendations made by Pellas et al. (2021) who concurrently advocate over the adoption of Virtual Reality (VR) as a means of supplementing the conventional didactic procedures or as a substitute of the hands-on activities that learners would otherwise perform in laboratories but are unable to. The same authors have also proposed the adoption of stereoscopic 360°-VR devices, especially for school-level courses, as the available technological resources and time are limited. Harada and Ohyama (2022) attribute the added value of this technology to the opportunity offered to learners to explore abstract concepts freely and safely. Another advantage of low-immersion VR solutions, like the *VeeR Mini Goggles*, is their inherent potential to render the virtual scenes from different angles and points of view. This contributes to the development of spatial awareness and, consequently, leads to the experience of the sense of physical presence.

The aforementioned studies also underline the scarcity of comparative studies to provide a clear distinction regarding the central premises that each approach influences. In greater detail, studies that have been conducted in the context of secondary education, with the focus being on the subject of MB, report findings to measure learners' achievements and outcomes without, however, considering the impact of the media effects on their motivation and engagement (Hodges et al., 2021; Wu et al., 2021). The only relevant research work identified is that of Erbas and Demirer (2019), who explored the potential of Augmented Reality (AR) in Biology over that of the traditional approach enriched by the aid of tablet devices, in terms of academic achievement and motivation. Therefore, a prominent research direction is identified where different media solutions are examined in view of both learning experience (media effect on motivation and engagement) and educational outcomes (attainment of the learning objectives, impact on knowledge gains).

In consideration of the aforementioned claims, the present study comparatively investigates the educational potential and impact that VR and educational videos have on learners' academic performance and motivation. To contextualise the study further, the following research questions (RQs) were proposed and addressed:

RQ1: Are students who engage with the stereoscopic 360 VR-supported instructional method performing better in the learning process compared to those who are instructed with the video-based multimedia instruction?

RQ2: Are students who engage with the stereoscopic 360° VR-supported instructional method more motivated compared to those who are instructed with the video-based multimedia instruction?

## BACKGROUND

### Video-based instruction

Biology instructors face several challenges not only in supporting learners' theoretical knowledge development but also in assisting their conceptual and practical understanding. A proposed solution to overcome this shortcoming is the adoption of alternative instruc-

tional methods as a supplement to the conventional ones. Relevant studies (Lei et al., 2015; Marsteller & Bodzin, 2015; Monkovic et al., 2021) that have introduced video simulations to the teaching-and-learning practices have found positive effects on both learners' motivation and knowledge advancement. The added-value of this approach is attributed to the potential that such multimedia tools offer in blending visual and auditory features with text and animated graphics.

In consideration of the above, the most positive effects of video-based multimedia instruction can be summarised as follows: (a) the integration of multimedia elements in education has been linked to increased learning performance (Lei et al., 2015), (b) the introduction of pop-up videos, as a means of complementing 3D printing procedures, has been found to have positive impact on the development of learners' procedural understanding (Monkovic et al., 2021), (c) the utilisation of web-based video instruction has been linked to increased memory retention and knowledge recall in process-oriented tasks (Marsteller & Bodzin, 2015), (d) the integration of storytelling scenarios in MB has been found to be an adequate alternative option for information-sharing (Goodsell et al., 2021), and (e) the adoption of haptic-enabled videos has been proven to be a valuable asset in assisting instructors to better understanding how learners' (metaphorical) gestures are associated with knowledge acquisition, especially when abstract concepts of biological processes are explored (Musaeus & Musaeus, 2021).

Other researchers (Green et al., 2018; Pirker & Dengel, 2021) have proposed the adoption of instructional videos provided by educationalists or non-profit organisations on online platforms (eg, Khan Academy, YouTube) for the following reasons: (a) they are well-known and widely used platforms, thus individuals are already familiar with the embedded features and functionalities, (b) they offer quality content provided by both academics and industry professionals without embedded costs, (c) they provide a wide variety of videos that cover similar or identical topics from different perspectives and points of view, and (d) the scientific content uploaded by verified providers—be it simulation videos or pre-recorded activities from the real-world setting—is considered to be highly accurate and robust.

However, various concerns have also been raised regarding the efficiency of this instructional approach. For instance, Lei et al. (2015) highlighted the extensive time required for the preparation of the educational videos as well as the limited opportunities that educators have during the contact teaching time to engage learners in reflective activities. Marsteller and Bodzin (2015) argue that educational videos lack directness and that leads to the development of misconceptions which, naturally, negatively impacts the knowledge acquisition. Goodsell et al. (2021) have observed that students show reduced interest in video learning resources due to the limited opportunities offered for natural interaction with the digital elements.

## Stereoscopic 360° VR-based instruction

The recent advancements in VR provide a wide variety of solutions which aim at improving the realism of the experience and enhancing users' spatial presence. Indeed, the dynamic visualisation or manipulation of abstract concepts is regarded as an essential component for the delivery of an authentic learning experience. Such affordances, individually and collectively, contribute towards the development of the so-called sense of presence (ie, the illusion of being present in the virtual environment) which is one of the key factors influencing user engagement and satisfaction. VR-based instruction enables learners to immerse themselves in the three-dimensional (3D) artificial environment via which the learning material acquires a more naturalistic form and the feedback loop is not only pointing at faults but also provides indicators that aid in identifying the correct solution (Pellas et al., 2021).

So far, the most prominent VR solutions that have been explored in the educational context can be classified into two broad categories: (a) high-end immersive VR, which delivers the content via standalone or tethered Head-Mounted Displays (HMDs), with high visual quality view and low latency framerates (Oculus Rift, HTC Vive) and (b) low-end immersive VR, which renders custom-made 360° videos in a spherical view and displays the content in budget-friendly equipment that is compatible with most modern smartphone devices (Google Cardboard, Wave VR box). The first is more appropriate for self-contained experiences (practice-based learning) but the relatively high cost of the hardware equipment and the time required to set up the activities make them relatively prohibitive for the casual learning context (Uz-Bilgin & Thompson, 2021). The second one is preferred when considering the conduct of large-scale interventions (experimental activities or situational training) due to its inconspicuous cost and the ease of deployment (ie, a smartphone paired with a portable VR cardboard) (Wu et al., 2021).

Researchers (Harada & Ohyama, 2022; Moro et al., 2021) who have explored systematically the potential of such technologies in biomedical science instruction have identified the following advantages: (a) it reduces the mental effort (internal factor) required to recognise and process abstract structures as well as their unique elements and features, (b) it reduces the mental load (external factor) by providing learners with points of reference that facilitate the conduct of hands-on tasks, (c) it improves visual cognition, via the repeated representations and conceptual illustrations of the real-world context, which make certain stimuli become automatic, and (d) it enhances learners' mental capacities (working memory)—via the rich, multi-sensory, feedback—which are needed for new knowledge and skills to be developed and acquired, respectively.

Educational researchers (Pellas et al., 2021; Pirker & Dengel, 2021) who have comparatively explored the potential of the aforementioned solutions have drawn the following conclusions: (a) designers and programmers need less time to create 360° videos as opposed to developing a VR simulation, (b) in high-end VR, the simulation sickness symptoms are milder due to the reduced latency rate, and (c) the first-person experience that VR generally offers contributes to the development of a higher degree of immersion.

The literature also highlights the potentials that VR offers in the subject of MB. The most important are: (a) the development of the sense of spatial presence, attributed to the high-fidelity representations, which increases the incentives to explore the scientific phenomena in greater depth (Blikstein et al., 2016), (b) the integration of game-based activities to present and communicate information related to complex structural elements and factual processes, attributed to the ludic and playful nature that such environments inherently have, which increases the retention and transfer of the constructed scientific knowledge (Wang et al., 2019), (c) the augmentation of the experimental activities, attributed to the multimodal interaction that the specialised apparatus offers, which increases the incentives for engagement (Uz-Bilgin & Thompson, 2021), and (d) the conduct of high-end simulated laboratory activities, attributed to the technical capabilities that modern VR platforms offer, which greatly enhance learners' cognitive and problem-solving skills (Wu et al., 2021).

Some of the above-mentioned studies (eg, Uz-Bilgin & Thompson, 2021; Wu et al., 2021) have also identified the added-value of stereoscopic 360° VR in MB for the following reasons: (a) the high-representational fidelity (eg, 3D depth, dynamic movements) enables learners to develop spatial awareness and experience the sense of presence; both of these elements have been widely attributed to improving knowledge acquisition and disciplinary understanding, (b) the observational narrative of scientific phenomena or situations enables learners to interpret information in a more diverse and logical way with a lower cognitive/mental effort and (c) instructional activities that take place in such environments enable teachers to communicate abstract concepts that often request that students utilise their critical thinking and analytical skills.

Beyond the novelty effect, previous studies related to the integration of VR in the educational context have also highlighted the following drawbacks and constraints: (a) high-end technological equipment is costly and inefficient in large group settings (Hodges et al., 2021); therefore, the adoption of low-end immersive VR devices is recommended (Wu et al., 2021), (b) accessibility and usability issues may prevent learners from engaging with the learning material or the exercises in a meaningful way; therefore, the integration of experiences that have been designed with simplicity and flexibility in mind is recommended (Blikstein et al., 2016), and (c) media-related factors that positively influence the user experience in high-end VR solutions (high quality of graphics, multimodal interaction), or else, negatively impact the user experience in low-end solutions (dizziness, fatigue), are irrelevant to knowledge acquisition or disciplinary understanding (Uz-Bilgin & Thompson, 2021).

## METHOD

### Research context

In the present work our aim was to comparatively examine the application of alternative digital instructional approaches in the physical classroom context, after considering all the situational limitations and spatio-temporal constraints that such an environment naturally poses. Based on the formal analysis performed on the course curricula, the module 'Life and Evolution' was deemed to be the one with the most abstract and complex topics. The instructional and assessment activities were designed in collaboration with the local high school teachers who also joined with their classes. To reduce the impact of our interference, the intervention was conducted in accordance with the predefined timetable, as recommended by the teachers in charge, and further encouraged by the school principal.

During the planning phase, the local regional manager of the upper secondary schools, as well as the school principal, examined and approved the research plan. The aforementioned permissions were sought in collaboration with the biology teachers who aided the conduct of the intervention. Prior to engaging students in the experimental activities, students were provided with detailed information regarding the scope and nature of the study, both in writing and verbally. Students who expressed an interest in participating were asked to counter-sign an informed consent form which included information about the following: (a) warnings of known possible side-effects that might occur while using the VR headset (eg, nausea, epilepsy), (b) information about the collection and use of their data and (c) their right to withdraw from the study at any point without any consequence. All sensitive data were handled in accordance with the General Data Protection Regulation (GDPR) guidelines.

### Instructional design

The approach followed in the present work follows, to some degree, the structure of the intervention that Erbas and Demirer (2019) conducted. The key differences across the studies are: (a) the replacement of the AR technology with that of the VR as well as the replacement of the traditional teaching approach (schoolbook) with that of the video and (b) the evaluation of three curriculum topics (Table 1) of which one (*Cells*) is comparable in complexity to the former study.

The instructional material (Figure 1) and the respective assessment tasks were aligned to the guidelines provided in the teacher's handbook. Nonetheless, given that the proposed interventions constituted the main didactic method, it was deemed worthwhile to increase and enrich the educational content so that students can delve into the topics in greater depth

and breadth. In line with this decision, we strictly followed the classroom timeline and delivered each lesson as a complete cycle. This enabled students to explore the concepts under investigation, understand the key information and finally apply the acquired knowledge at once.

## Research design

For the investigation of the RQs, we employed the quasi-experimental design approach with repeated measurements (Privitera & Ahlgrim-DeLzell, 2018). As a point of reference (control condition), we considered the intervention with the use of Video Learning Resources (VLR), as students are more acquainted with this instructional method (Lei et al., 2015). In the other approach (experimental condition), the intervention involved the adoption of a low-end mobile-VR solution (*VeeR Mini VR Goggles*). To eliminate the distribution bias, we followed the non-randomised sample approach (Campbell & Stanley, 2015).

In addition, as underlined by the review of the literature, Biology is a challenging subject and this can possibly have an effect on learners' interest. This is the reason why it was deemed worthwhile to check if the effects of instructional methods were limited or not due to the learners' prior interest in the subject under investigation. Another aspect taken into consideration was the potential non-familiarity with the adopted technologies and its impact on motivation for any of the two methods. Finally, experimental studies that utilise VR solutions often mention cybersickness symptoms.

## Procedures

The educational intervention was conducted in five consecutive weeks (Figure 2). During the first session (week 1) participants were requested to provide the following information in order to enable the research team form the cohorts (Experimental Group—EG/Control Group—CG): (a) gender, (b) prior experience with similar digital learning tools (VR/VLR), (c) cybersickness history, and (d) interest in Biology. In addition, a knowledge assessment form (pretest), covering issues related to the topics to be taught in the forthcoming sessions, was distributed so as to gauge the starting knowledge level of the participants.

Taking the above parameters into account, the research team divided the individuals into two distinct groups (CG—VLR, EG—VR). This enabled us to achieve an equal-sample size distribution across the cohorts and an almost equal gender variation which helped in

TABLE 1 Overview of the learning objectives as defined in the curriculum (<https://www.oph.fi/en/education-and-qualifications/subjects-general-upper-secondary>).

Theme	Learning objectives
Cells	Understand the structures and purposes of basic components of prokaryotic and eukaryotic cells, especially macromolecules, membranes and organelles Understand how these cellular components are used to generate and utilise energy in cells Understand the cellular components underlying mitotic cell division
Genetics	Learn the basic principles of inheritance at the molecular, cellular and organismal levels Understand causal relationships between molecule/cell level phenomena (“modern” genetics) and organism-level patterns of heredity (“classical” genetics) Understand the source of genetic variation and how it is shaped in the absence of selection
Evolution	Understand the evidence that living species share descent from common ancestry and how this fact explains the traits of living species Understand that evolution entails changes in the genetic composition of populations

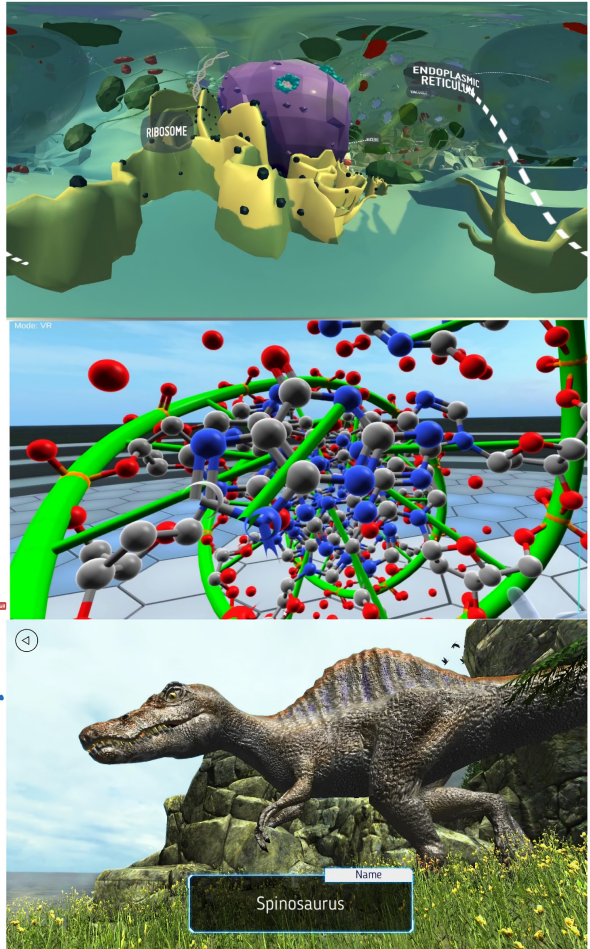
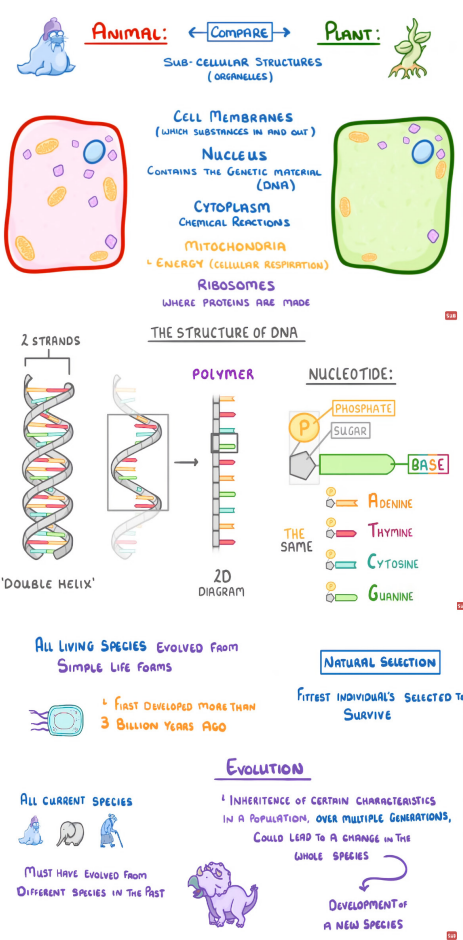


FIGURE 1 Comparative presentation of the digital instructional material (left—VLR, right—VR).

eliminating the gender bias (Rafferty & Valiulis, 2008). The latter further allowed us to explore the impact that gender plays in science-related topics (Buccheri et al., 2011). Additionally, it enabled us to control the possible impact that the novelty effect or the cybersickness may have had on the participants of the experimental group (Huang et al., 2021).

In the following three weeks, the classroom sessions were dedicated to the teaching of the chosen topics using the described instructional approaches. The classroom session time was split in three parts: (a) a brief seminar delivered by the teachers in charge of the subject under investigation, (b) use of the assigned digital instructional tool and (c) knowledge assessment (weekly and conclusive). For the conduct of the intervention, all participants utilised their own mobile devices, including headphones, to maintain the classroom noise-levels as low as possible. Additionally, participants of the EG, were provided by the research team with the stand-alone VR goggles. Students of both groups were deliberately allowed to view the instructional material for as long as was deemed necessary including moving forward/backward. As for the interplay part, students from the EG had an extra advantage that the VR devices offer over their counterparts (ie, the 360° stereoscopic view). The weekly knowledge assessments covered part of the exercises that students would otherwise have to complete as part of their homework.

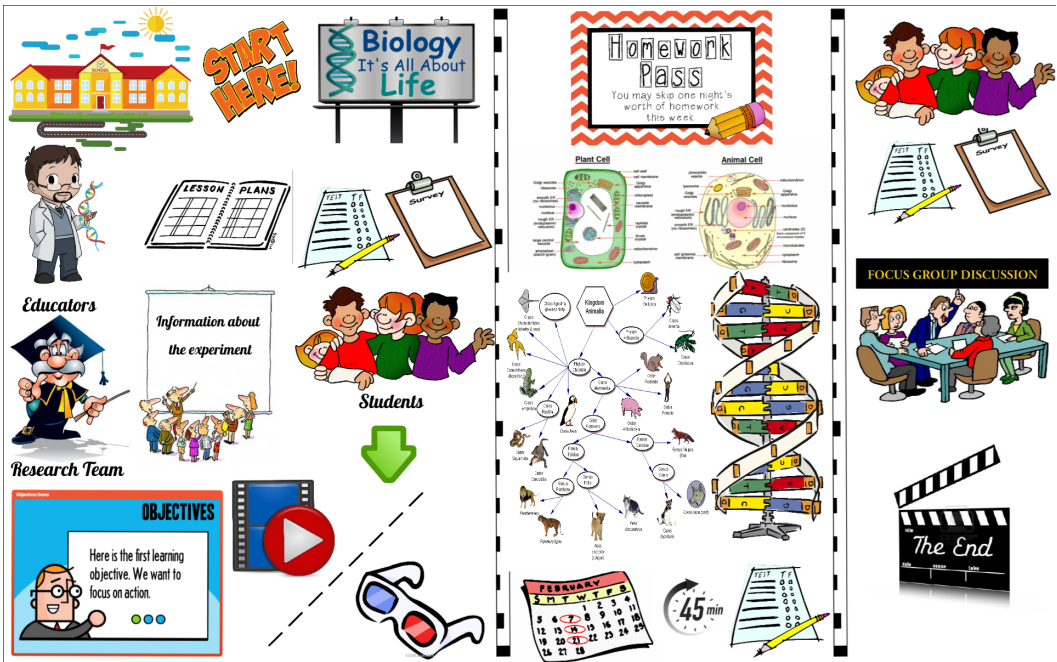


FIGURE 2 Overview of the experimental procedures.

The experiment concluded one week after the final training session during which an all-inclusive assessment (posttest) was distributed to the participants along with the psychometric survey that examined their views and perceptions over the integrated instructional approaches.

## Participants

The reference population consisted of upper secondary school students ( $n = 70$ ) who were divided as follows: the CG (males = 18, females = 17), which adopted the VLR, and the EG (males = 16, females = 19), which adopted the stereoscopic 360° VR-based instruction.

## Instruments

The preliminary survey utilised to divide students in groups covered the following topics: (a) background information (demographics, English level and interest in Biology), (b) prior experience in utilising instructional methods like the ones adopted in the context of this study (VR/VLR) measured on a 5-point Likert-scale, and (c) history of experience consequences (fatigue, headache, eyestrain, nausea), when considering VR equipment (headsets, goggles) using, once again, a 5-point Likert-scale.

The students' academic and conceptual knowledge (Figure 3) was evaluated from the following perspectives: (a) retention (retrieving existing knowledge—pretest), (b) near transfer (drawing accurate conclusions—intermediate assessment), and (c) far transfer (applying knowledge—posttest).

The pre-intervention diagnostic assessment (pretest) consisted of a small set of multiple-choice questions covering a broad spectrum of knowledge that students may have

had on the topics they were about to be taught. These assessments were used to compare the initial knowledge of the two groups. The intermediate assessments included exercises (classification, ordering, open-ended) and quizzes (multiple-choice questions) on the subject taught each week. These assessments were used to verify if satisfactory learning was achieved, as would be indicated by scores higher than 0.50, and to compare any differences between the groups. For the conclusive assessment (posttest), we selected the assignments that challenged students the most during the intermediate assessments. This was done to prevent ceiling effects. These scores were used to assess differences in the learning outcomes of VLR and VR.

For the evaluation of motivation, the *Relevance*, *Attention* and *Satisfaction* scales of the 'Instructional Materials Motivation Survey' (Keller, 2010) were translated to students' native language using the backtranslation method (Brislin, 1970).

The scales consisted of five Likert-scale points (1—Not true; 2—Slightly true; 3—Moderately true; 4—Mostly true; 5—Very true). Previous research (Keller, 2010) has demonstrated good to excellent internal consistencies, with Cronbach's alpha of 0.81 for the *Attention* scale (12 items), 0.92 for the *Satisfaction* scale (6 items) and 0.90 for the *Relevance* scale (9 items). The *Attention* subscale measures how well the course helps to avoid boredom and succeeds in capturing and maintaining students' attention. The *Satisfaction* subscale measures enjoyment and experienced accomplishment during and after the course. The *Relevance* scales measure if participants feel that the course links to one's prior knowledge and skills, current needs, as well as future use and applications. The items of the scales can be found in Appendix A. The dissemination of all data collection forms was supported by the Learning Management System that the school utilises.

### Data analysis

Data processing was performed by the lead author alone with the intention of protecting the individuals' identity. For the analysis of the performance metrics, an adaptive scoring

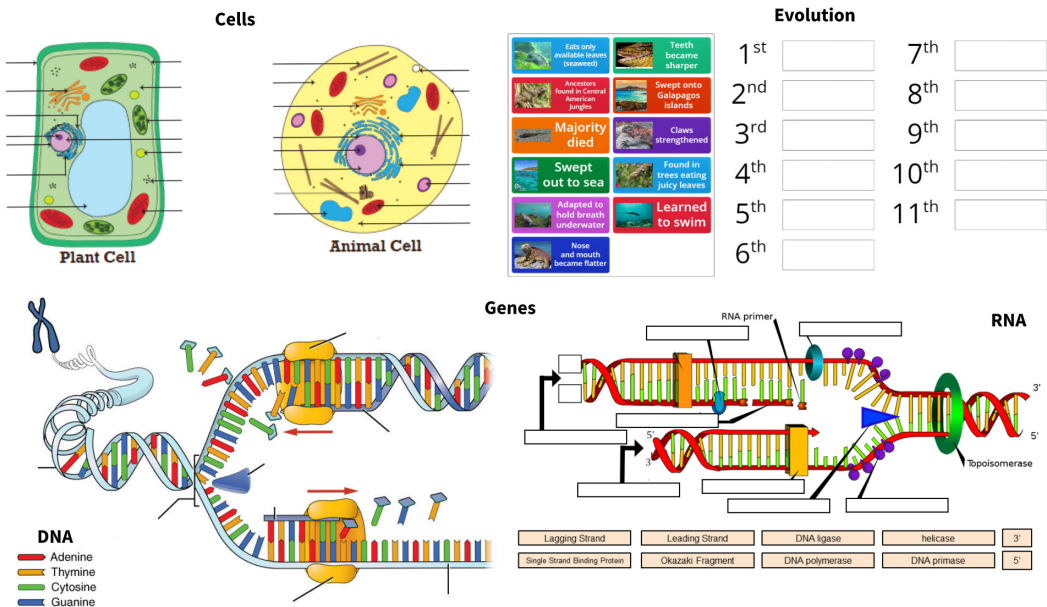


FIGURE 3 Indicative examples of the exercises used for the knowledge assessment.

method (Bridgeman & Cline, 2004) was delivered where incorrect answers received 0 points, partially correct answers 0.5 points and correct answers were awarded 1 point. To facilitate interpretation, the total assessment scores for each topic were subsequently calculated by taking the average of all the associated test questions. The outcomes of the performance results were utilised explicitly for the needs of the present study (ie, no impact on the participants' school performance). For the analysis of the learning experiences, we composed the subscale scores by taking the average of the associated items.

The dataset was initially explored via descriptive statistics and subsequently analysed using inferential methods. The analysis was done with SPSS (ver.28). Outliers were analysed, and for this we used a  $z$ -criterion score of 3.29, and calculated the standardised scores for this purpose (Field, 2018). For the determination of normality, we followed the guidelines given by Kim (2013). Assessment scores were compared to a criterion value by using one-sample  $t$ -tests or, in case of violation of the normality criterion, by using non-parametric one-sample Wilcoxon Signed Rank tests. The group comparisons were made using independent sample  $t$ -tests or the non-parametric Mann–Whitney  $U$  test. As there was a small gender difference within the sample, we also wished to control for any gender effects. We were also careful to control for other possible co-variables, being: interest, familiarity and pre-assessment scores. This was done using Analysis of Covariance (ANCOVA).

For the comparisons of learning experiences, Mann–Whitney  $U$  tests were used, as the distributions of the subscales were shown to deviate from normality. We also used Mann–Whitney  $U$  tests to make gender comparisons and investigated correlations with interest and familiarity by Spearman  $\rho$  correlations.

## RESULTS

### Demographics

The sample characteristics of the CG and the EG are presented in Table 2. As can be seen, gender was almost equally distributed in both groups. They had at least an intermediate level of English and most learners were of an advanced or proficient level. Familiarity with VR was lower in the EG compared to familiarity with VLR in the CG, depicting the fact that VR is still less commonly used in education. As such, it was not possible to create equality between the groups in familiarity. However, we made sure that the groups had the same or similar interest in biology. It is noteworthy that all students were at least slightly interested.

### Academic performance

Analyses of outliers revealed that there were no extreme scores (with extreme scores defined as  $z$ -score  $>3.29$ ). The descriptive statistics for all assessments at the pre- and intermediate-test are presented in Table 3. Following the directions of Kim (2013) for small samples, we calculated the  $z$ -scores of skewness and kurtosis to evaluate normality, which are determined by dividing the skew values or excess kurtosis by their standard errors. This led to the conclusion that the assessment scores about *Cells* showed some deviation from normality in the EG; with the pre-intervention scores being negatively skewed ( $p = 0.013$ ); and the intermediate assessment showing a positive skew ( $p = 0.023$ ). For this reason, non-parametric tests were used when analysing these test scores. All other variables showed fairly normal distributions. It is further notable that the scores were relatively most spread in the intermediate test about *Genetics*, which was true in both groups.

TABLE 2 Participants' demographic and background information.

Demographics/background	Control group (VLR)		Experimental group (stereoscopic 360° VR)	
	<i>n</i>	%	<i>n</i>	%
Gender				
Males	18	51.43	16	45.71
Females	17	48.57	19	54.29
Prefer not to answer	0	0.00	0	0.00
English level				
Beginner	0	0.00	0	0.00
Intermediate	2	5.71	6	17.14
Advanced	10	28.57	14	40.00
Proficient	23	65.71	15	42.86
Familiarity with VLR/VR				
Not at all familiar	0	0.00	4	11.43
Slightly familiar	0	0.00	14	40.00
Somewhat familiar	15	42.86	14	40.00
Moderately familiar	9	25.71	3	8.57
Extremely familiar	11	31.43	0	0.00
Interest in biology				
Not at all interested	0	0.00	0	0.00
Slightly interested	8	22.86	8	22.86
Somewhat interested	19	54.29	19	54.29
Moderately interested	6	17.14	6	17.14
Extremely interested	2	5.71	2	5.71

One sample Wilcoxon Signed Rank tests showed that, in both groups, the median pre-assessment scores about *Cells* were significantly below the criterion value of 0.50 (Table 3), with a median score of 0.40. It was further found that the mean scores on *Genetics* were significantly below 0.50 for both groups (Table 3). The scores on *Evolution*, however, did not significantly differ from 0.50. This indicates that at the start students knew relatively most about *Evolution*. There were no significant differences between the groups in the scores on the pre-assessment (last column of Table 3).

In both groups, the intermediate median scores on *Cells* were 0.70, and these were significantly higher than the criterion value of 0.50 (Table 3). For *Genetics*, only the EG had a mean that was significantly higher than 0.50, with the average score of 0.53 achieved by the CG revealing no significant difference from 0.50. However, the difference between the two conditions was small and did not reach significance (Table 3). The mean scores on *Evolution* were significantly higher than 0.50, with again no significant difference between the CG and the EG (Table 3). In conclusion, these results suggest that students in both conditions had satisfactory intermediate assessment scores.

We then looked at the post-assessment scores. The reader is reminded that here we did not have a specific criterion, as these assignments consisted of questions that were selected as *the most challenging* on the intermediate tests. As such, they were more difficult than what a normal end-module assessment would be. The purpose was to test the first research question, that is, if students in the EG would obtain better learning performance. Even though, overall, the scores of the EG seemed slightly higher, independent sample *t*-tests showed no

TABLE 3 Descriptive statistics for the pre- and intermediate assessment results.

Test	Control group				Experimental group				Condition difference test
	M	SD	Test for difference from 0.50	p	M	SD	Test for difference from 0.50	p	
Pre-assessment									
Cells	0.41	0.13	$z = -3.53$	<0.001	0.39	0.10	$z = -4.52$	<0.001	$z = -0.72, p = 0.475$
Genetics	0.35	0.13	$t(34) = -6.70$	<0.001	0.35	0.11	$t(34) = -7.52$	<0.001	$t(68) = -0.19, p = 0.848$
Evolution	0.48	0.13	$t(34) = -1.05$	0.300	0.47	0.09	$t(34) = -1.97$	0.058	$t(68) = 0.41, p = 0.828$
Intermediate assessment									
Cells	0.67	0.13	$z = 4.81$	<0.001	0.69	0.12	$z = 5.02$	<0.001	$z = -0.85, p = 0.394$
Genetics	0.53	0.29	$t(34) = 0.70$	0.490	0.59	0.20	$t(34) = 2.83$	0.008	$t(68) = -1.01, p = 0.316$
Evolution	0.64	0.16	$t(34) = 5.20$	<0.001	0.68	0.14	$t(34) = 7.51$	<0.001	$t(68) = -1.04, p = 0.303$

Note: Test for difference from 0.50 represent one sample *t*-tests, except for Cells where Wilcoxon Signed Rank tests were carried out as the non-parametric alternative. Similarly, Condition Difference tests are independent sample *t*-tests, except for Cells where Mann–Whitney tests were carried out.

differences between the students in the two conditions for *Cells* ( $t(68) = -1.42, p = 0.160$ ), *Genetics* ( $t(68) = -1.60, p = 0.114$ ) or *Evolution* ( $t(68) = -1.60, p = 0.173$ ).

We then performed Analysis of Covariance (ANCOVA) to control if still no differences would be found controlling for any gender effects, interest, familiarity, or—more importantly—the pre-intervention scores. The ANCOVA for the post-assessment test about cells revealed no condition effect,  $F(1, 62) = 0.67, p = 0.417$ , no gender effect,  $F(1, 62) = 1.35, p = 0.249$ , and no Condition  $\times$  Gender effect,  $F(1, 62) = 1.90, p = 0.173$ . None of the covariates was significant either. Similarly, for the post-assessment about genetics, no condition effect,  $F(1, 62) = 0.21, p = 0.650$ , no gender effect,  $F(1, 62) = 0.62, p = 0.436$  and no Condition  $\times$  Gender effect,  $F(1, 62) = 0.01, p = 0.916$  was found, and again none of the covariates were significant. Finally, again for the post-assessment about evolution, no condition effect,  $F(1, 62) = 0.48, p = 0.491$ , no gender effect,  $F(1, 62) = 0.93, p = 0.340$  and no Condition  $\times$  Gender effect,  $F(1, 62) = 0.56, p = 0.457$ . The covariates also were not significant. As such, we have to conclude that similar learning effects were obtained in the experimental and control condition.

## Motivation

In the current study, excellent internal consistencies were found ranging from  $\alpha = 0.90$  for *Satisfaction*,  $\alpha = 0.92$  for *Relevance* and  $\alpha = 0.95$  for *Attention*. There were no extreme outliers on the scales measuring the students' motivation.

Overall, the distributions seemed to be higher for the EG. However, different distributions were found for the two conditions. The scores of students in the CG showing more platykurtic distributions (which means flatter peaks and thinner tails), as demonstrated by negative excess kurtosis of  $-1.74, -1.69$  and  $-1.68$ . The scores of the students in the experimental condition showed negative skewness of  $-1.51, -1.37$  and  $-1.47$ , indicating a pile-up of scores on the higher ranges of the scales. Therefore, non-parametric tests were used to compare the scores of the two groups. The means, standard deviations and median scores

along with the Mann–Whitney  $U$  tests for comparison of the CG and CG are presented in Table 4. The EG reported significantly higher relevance and attention compared to the CG, and also experienced more satisfaction than the CG. As such, it is concluded that the motivation was, overall, higher in the EG.

Separate gender comparisons for each condition revealed similar motivational experiences for boys and girls, with  $U = 130$ ,  $z = -0.78$ ,  $p = 0.434$  for *Relevance*,  $U = 130$ ,  $z = -0.81$ ,  $p = 0.420$  for *Attention* and  $U = 130.5$ ,  $z = -0.76$ ,  $p = 0.447$  for *Satisfaction* in the CG, and with  $U = 130.5$ ,  $z = -0.80$ ,  $p = 0.421$  for *Relevance*,  $U = 112.5$ ,  $z = -1.38$ ,  $p = 0.169$  for *Attention* and  $U = 115$ ,  $z = -1.38$ ,  $p = 0.169$  for *Satisfaction* in the EG.

Spearman  $\rho$  correlations were investigated to find out if the motivation ratings were associated with familiarity and interest (Table 5). It was found that only in the CG familiarity was negatively associated with motivation. This means that students who were already more familiar with VLR were less positive about the *Relevance*, *Attention* and *Satisfaction* they perceived.

## DISCUSSION

The results of this study show that the stereoscopic 360°-VR instruction does not result in better learning outcomes than VLR instruction. We had expected that the stereoscopic 360°-VR condition would maybe result in better learning outcomes, as it provides a more realistic experience (Blikstein et al., 2016) and enhanced spatial learning possibilities (Pellas et al., 2021). However, it appeared that equally good and quite similar results were achieved in both conditions. This finding extends the conclusions that Uz-Bilgin and Thompson (2021) reached regarding the absence of impact on knowledge acquisition or conceptual understanding when comparing the effectiveness of high-end VR to low-end VR. These results are also in line with those of Erbas and Demirer (2019), who have also failed to demonstrate improved performance in Biology when using AR compared to the use of tablets only. As such, it seems that even 'normal' visualisations are sufficient to obtain knowledge in biology as well as other molecular topics.

TABLE 4 Descriptive statistics for motivation.

Test	Control group			Experimental group			$U$	$z$	$p$
	$M$	$SD$	$Mdn$	$M$	$SD$	$Mdn$			
Relevance	3.14	0.96	2.33	3.97	0.42	4.22	381	2.81	0.005
Attention	3.16	0.93	2.42	4.11	0.40	4.17	281	3.98	<0.001
Satisfaction	3.05	0.99	2.50	4.17	0.43	4.33	163	5.40	<0.001
Total Motivation	3.13	0.95	2.37	4.08	0.41	4.22	233	4.50	<0.001

TABLE 5 Spearman  $\rho$  correlations between familiarity and interest and motivation.

Variable	Control group		Experimental group	
	Familiarity	Interest	Familiarity	Interest
Relevance	-0.46**	0.04	0.11	-0.19
Attention	-0.54	0.04	0.01	-0.03
Satisfaction	-0.43**	0.02	0.11	-0.16
Total motivation	-0.43**	0.02	0.04	-0.06

\*\* $p < 0.05$ .

The baseline knowledge about the topic of *Evolution* was the only one whose questions—about half of them—students were already able to complete correctly. This is so because this topic is probably more common in daily conversations and media compared to *Genetics* and *Cells*. Overall, it is demonstrated that students can indeed learn these latter more complicated topics with the aid of visualisations. Previous research has also confirmed that topics such as *Cells* and *Genetics* are considered as particularly difficult for students and that visualisations are appreciated in the learning process (Goodsell et al., 2021); something that was again confirmed by the current study.

As far as the motivational aspect is concerned, the use of stereoscopic 360° VR has a considerable advantage. This is an important finding, as it means not only that it was more pleasurable for students (c.f. lack of student interest in VLR as also indicated by Goodsell et al., 2021) but also that they will remember what they have learned for much longer, as Wang et al. (2019) also claim. Interestingly, familiarity with VLR was associated with less positive learning experiences. It might be that for some students, the videos were too similar to those they had previously seen, making them less motivating. This association was not found in the case of familiarity with stereoscopic 360°-VR devices. This might be because students were less familiar with VR. It could, therefore, be concluded that, once VR is used more frequently in education, some of the positive effects might be reversely affected by this as well.

The findings of this study are also consistent with previous works (Blikstein et al., 2016; Wang et al., 2019) which suggest that even low-cost stereoscopic 360° VR headsets can provide a more realistic and stimulating experience when compared to the restrictive intuitiveness that video-based instruction offers. Indeed, in contrast to the simplified and flat design that the video interface delivers, stereoscopic 360° VR utilises dual multimedia channels to blend the spectrum of fantasy with realism and create a digital story-like narrative which urges the eyes and the brain to work together (Fuchsova & Korenova, 2019).

As students will also get more acquainted with stereoscopic 360° VR outside the educational school setting, they may start to expect the use of it in education as well. Moreover, with advancing techniques, VR possibilities might be further improved over time, resulting in better learning outcomes. This is why researchers (Pellas et al., 2021; Pirker & Dengel, 2021) recommended further research on the possibilities and the technical aspects of such technology. Therefore, more research is necessary to understand which stereoscopic 360° VR possibilities might help instructions to enhance specific topics and how this can be attained. Motivation for STEM (Science [including Biology], Technology, Engineering and Mathematics) is often considered to be low and even problematic among secondary school students, especially among girls (Salmela-Aro, 2020). The fact that there were no gender differences, neither in performance, nor in motivation, demonstrates that the utilised instructional methods seem to decrease the gender gap that is normally found with respect to STEM.

It is of significant importance that, in the current study, motivation was measured with respect to not only satisfaction and attention but also perceived relevance. As such, the intervention was successful in motivating the participants in all respects. This has potential for the intervention. As argued by Pellas et al. (2021), education should show constructive alignment; students should learn and be assessed in a way that aligns with the desired outcomes. The fact that students reported their feeling that what they were learning was relevant means they see actual utility, and will probably be able to indeed apply what they have learned. It can be difficult for Biology topics to be instructed in a way that students find enjoyable, and it can be even more difficult to educate topics in a way that students find purposeful and practical in out-of-class experiences (Heddy & Sinatra, 2013). Compared to satisfaction and attention, relevance in the experimental group still received the lowest rating, suggesting that it was easier to elevate satisfaction and attention in the case of more in-the-moment experiences. Still, the score was high in the scale, and higher than in the CG. A crucial finding that can,

therefore, be concluded is that even though both instructional approaches (VR/VLR) have similar effects on learning, VR did influence motivation—including experienced relevance—to a greater extent.

## CONCLUSION

Biology in secondary education seeks primarily to cultivate students' interest in biological and environmental matters and secondarily to develop their scientific thinking. Among the key competencies that students need to develop are the ability to interpret biological phenomena and situations, as well as the capacity to determine the causes of possible environmental problems. In the European school context, MB is mainly streamlined over the evolution of living organisms covering topics spanning from molecular and cellular levels to the biosphere. In order for learners to develop such cognitive attributes, the adoption of learning modalities that promote active exploration and experimentation through guided discovery is deemed as essential (Hodges et al., 2021).

However, textbooks still constitute the main approach for transmitting knowledge with the aid of multimedia recourses (videos, PowerPoint slides) to support the whole instructional process being occasional only. To this end, the adoption of VR in the mainstream teaching-and-learning practices is still prohibitive due to the relatively high cost of the specialised apparatus or the demanding nature that the integration procedures present. This justifies the reasons for which relevant studies (Makransky et al., 2019; Walker, 2021) have been conducted in fully controlled environments (ie, VR laboratories).

In consideration of all of the above, this study explored the effectiveness of low-end VR instruction over that of video-based multimedia instruction on secondary school students' learning performance and motivation. The key findings indicate that students' performance is not affected from the integrated instructional approach, yet motivation is. In view of these findings, the implications for practice and policy are streamlined to the enhancement of students' experience which can be achieved by: (a) developing more open educational recourses; (b) designing instructional content with multidimensional elements, high-representational fidelity, and acoustic feedback; and (c) systematically introducing the adoption of simulations in abstract subjects (such as Biology). All the above can greatly facilitate the development of conceptual congruence and aid in the comprehension of knowledge during the scientific discovery process.

## LIMITATIONS AND FUTURE WORK

The limitations of the present work shape the directions for future research. First, the generalisation of the results cannot be extended beyond the local context, thus affecting the external validity of the study. The second limitation is the sample size. However, as educational researchers (Walker, 2021; Wang et al., 2019) have recommended, the small sample of participants enables instructors and researchers to evaluate students' learning performance and motivation in greater depth. The final limitation identified concerns the novelty effect. Although many efforts were made to diminish its impact, participants' norms and perceptions towards the integrated approaches—especially after considering the changes made in instruction due to the Covid-19 pandemic outbreak—may have influenced their learning behaviour and attitude towards technology.

Future works can explore the aforementioned topics and instructional tools utilising mixed-methods research design, ideally for a longer period of time, and with larger samples. Such studies will facilitate both the development of a better understanding over the potential

of the proposed approaches and the development of a more comprehensive classification of factors that influence students' behaviour and engagement, post the Covid-19 era, in both the short and the long term.

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## CONFLICT OF INTEREST STATEMENT

All authors declare that they have no conflicts of interest.

## DATA AVAILABILITY STATEMENT

The data sets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

## ETHICS STATEMENT

All procedures performed in studies involving human participants were following the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was also obtained from all individual participants included in the research as well as from their legal guardians/parents.

## PARTICIPATION IN THE STUDY

Informed consent was obtained from all individual participants involved in the study. Participants personal information were collected but the right to withdraw at any time was granted.

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## APPENDIX A

### Items of keller's instructional materials motivation survey subscales (attention, satisfaction and relevance)

Item code	Item
R1	It is clear to me how the content of this material is related to things I already know
R2	There were stories, pictures, or examples that showed me how this material could be important to some people
R3	Completing this lesson successfully was important to me
R4	The content of this material is relevant to my interests
R5	There are explanations or examples of how people use the knowledge in this lesson
R6	The content in this lesson conveys the impression that its content is worth knowing
R7*	This lesson was not relevant to my needs because I already knew most of it
R8	I could relate the content of this lesson to things I have seen, done, or thought about in my own life
R9	The content of this lesson will be useful to me
S1	Completing the exercises in this lesson gave me a satisfying feeling of accomplishment
S2	I enjoyed this lesson so much that I would like to know more about this topic
S3	I really enjoyed studying this lesson
S4	The wording of feedback after the exercises, or of other comments in this lesson, helped me feel rewarded for my effort
S5	It felt good to successfully complete this lesson
S6*	It was a pleasure to work on such a well-designed lesson
A1	There was something interesting at the beginning of this lesson that got my attention
A2	These materials are eye-catching
A3	The quality of the material helped to hold my attention
A4*	This lesson is so abstract that it was hard to keep my attention on it
A5*	The content of this lesson looks dry and unappealing
A6	The way the information is arranged helped keep my attention
A7	This lesson has things that stimulated my curiosity
A8*	The amount of repetition in this lesson caused me to get bored sometimes
A9	I learned some things that were surprising or unexpected
A10	The variety of reading passages, illustrations, etc., helped keep my attention on the lesson
A11*	The style of this material is boring
A12*	There is so many information that it is irritating

*Note:* In the item codes: A, attention; R, relevance; S, satisfaction. Asterisked items should be recoded prior to data analysis (1 = 5, 2 = 4, 4 = 2, and 5 = 1).