Multimedia based instructions on Visual Thinking Skills and Academic Achievement in Biology: A Systematic Review

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ARTICLE DETAILS	ABSTRACT
	This is a systematic review of multimedia based instructions on the ability to think visually and the academic performance specifically in biology education. The review offers the evidence of on pedagogical grounds. The consequence of the theoretical frameworks which integrate the cognitive load theory and the dual coding theory with the studies on spatial cognition are the theoretical explanations of the effect which is observed. The applicability of the findings to the curriculum, teacher development, as well as the use of educational technology in the teaching of biology, are significant. The effectiveness in various stages of education on the usage of spatial cognition and learning outcomes with the help of various multimedia technologies according to 30 peer-reviewed studies held between 2012 and 2025. These are the three-dimensional models, augmented reality, virtual reality and interactive visualizations. The analysis results shows that the multimedia interventions can produce a consistent positive impact on visual thinking skills and academic achievements whose effects are moderate and large respectively. The effectiveness of the following technologies, however is mediated by individual differences in spatial capabilities, instruction design effectiveness and dimensionality of representations. The review infers that augmented reality or three-

dimensional visualization is most promising to be used to teach complex biological structures but the strategies of implementation should be rooted

1. Introduction and Conceptual Framework

A pedagogical issue with biology education is the subject matter requires students to visualize and mentally manipulate complex and three-dimensional structures and processes that are normally not visible to the naked eye, such as subcellular organelles to organ systems and ecological associations. The conventional teaching systems using two-dimensional textbook diagrams and fixed models have not been adequate in the ability to acquire the advanced visual thinking skills required of the immersive comprehension of biology. This weakness has been more evident as modern biology educational programs tend to focus more on molecular processes, structural-functional correlation, and systems-level integration all that requires well-developed spatial reasoning skills. With the rise in the use of digital multimedia technologies in the last twenty years, the possibilities of changing the biology pedagogy are unprecedented. It is now possible to engage learners with the phenomena of biology in ways that were not possible before because of 3-D visualization software, augmented reality applications, and virtual reality environments and interactive simulations. Such technologies have the potential to close the divide between abstract conceptual learning and concrete spatial learning and may revolutionize the way students are taught to think visually and reach learning outcomes in the sciences such as biology. Nonetheless, the introduction of multimedia resources to biology education creates important questions, which should be explored in a systematic way.

The systematic review will answer the set of questions by integrating empirical studies that have been published within the last 10-15 years and more importantly, the research studies that investigate the topic of multimedia interventions with the measures of visual thinking skills and spatial abilities in addition to academic achievement. The review is based on a conceptual framework, which places multimedia resources in the role of instructional mediators, interacting with learning along a series of pathways: by lessening cognitive load with the aid of suitable representational formats, by deploying dual coding processes with simultaneous information processing of the verbal and visual data, and by giving scaffolded opportunities to the development of spatial reasoning skills that are transferred to the enhanced level of biological mastery and academic achievement.

This review is important in more than capturing effectiveness. Through a critical analysis of the theoretical aspects, methods of conducting the studies and the empirical data of the various studies, the review intends to establish design principles to successfully integrate multimedia, shed some light on the mechanisms of the observed effects and also indicate gaps that need to be filled by conducting further studies. The implications of the findings to curriculum developers, instructional designers, teacher educators, and policymakers are direct in terms of finding evidence-based ways of improving biology education in the ever-growing more technology-laden educational environment.

2. Objectives of the study

1. To examine the overall impact of multimedia instruction on academic achievement in biology across different stages.

2. To systematically review the existing studies published between 2012 and 2025, examining the impact of multimedia resources on visual thinking skills.

3. To compare the effectiveness of various multi modalistic model (e.g., 3D, Augmented reality, Virtual reality, etc) in biological education.

3. Theoretical Foundations

3.1 Cognitive Load Theory and Multimedia Learning

The cognitive load theory entails a theoretical basis of examining the effects of multimedia resources on the learning process. The theory is that human working memory possesses restricted amounts of processing capacity over a novel input, and that the instruction design needs to be as minimal as possible of extraneous cognitive load whilst being as germane cognitive load as possible channelled to schema construction and automation. People In terms of biology education, complex three-dimensional objects and dynamic processes may carry a significant intrinsic cognitive load, especially when they are shown in poor representational forms.

Multimedia technologies contribute to solving this issue by making use of several sensory modalities and representational systems to allocate cognitive processing in a more efficient manner. Studies show that carefully designed multimedia interventions have the potential to decrease extraneous load by removing split-attention effects, provision of spatial and temporal contiguity between verbal and visual stimuli, and interactive control of pacing and perspective. Biological education studies have empirically shown that learners working with three-dimensional visualizations have been observed to report greater levels of

germane cognitive load, which implies productive cognitive engagement, than those working with traditional two-dimensional visualizations, especially in regard to learning about spatially complex structures such as cardiac anatomy or cellular organization [2], [16].

Nevertheless, multimedia design and cognitive load are not connected in a positively uniform way. Poor multimedia design may add undue load in form of redundancy, over-visualization or wrong interactivity. A very subtle challenge is the dimensionality of representations: in as much as 3D models can provide more information about spatial information, they can also overload learners with low spatial skills who do not have the cognitive resources available to them to manipulate complex visualizations in their minds [2].

3.2 Dual Coding Theory

Dual Coding Theory is a complement to the Cognitive Load Theory because it reflects the ability of multimedia resources to complement verbal and visual information during parallel processing to learn more effectively. According to the theory, human cognition is facilitated by two functionally separate systems that are approximately connected: a verbal system that is specialized in the processing of linguistic information, and an imagery system that is specialized in the processing of nonverbal, spatial information. Learning is promoted when teaching resources stimulate systems as well as promote the establishment of referential relations between verbal and visual representations.

Biology education presents the perfect field in which dual coding processes can be practiced since the nature of the biological concepts requires structural-spatial knowledge and conceptual-linguistic knowledge. The multimedia technologies that combine three-dimensional visualization and an explanatory text or narration allow learners to build both representations and make associative connections between the two. Research on the use of augmented reality in biology has shown that a combination of interactive three-dimensional models and textual notations are more effective than using one modality or the other in the context of learning, which is consistent with the hypothesis of dual coding [1], [4].

Modern discussions in the field of multimedia learning research have narrowed down the dual coding theory with the consideration of the significance of time alignment, modality suitability, and learner control. The principles of spatial contiguity propose that both the verbal and visual information must be placed together and not apart physically, whereas the principles of temporal contiguity propose simultaneous presentation of information and not sequential. In education biological design concerns

have been translated into design suggestions, including integrating textual labels into three-dimensional anatomical structures or coordinating narration with cellular processes.

3.3 Spatial Cognition and Visual Thinking

The third theoretical pillar to the understanding of multimedia effects in biology education is the research on spatial cognition. Visual thinking is a body of cognitive skills such as mental rotation, spatial, visualization, perspective-taking, and the ability to manipulate mentally three-dimensional forms. Such skills do not simply accompany biological knowledge but are inherent to basic skills towards argumentation pertaining to structural-functional relations, developmental dynamics, and ecological dynamics. Personal difference: There is a significant individual difference in spatial abilities that affects learning using multimedia resources. Mental rotation skill the ability to mentally rotate objects in three dimensions has become a rather significant predictor of achievement in anatomy and biology classes. It was shown that, high spatial learners learn better through the use of three-dimensional visualizations whereas low spatial learners require extra scaffolding or prior training to successfully use the complex multimedia tools [16], [17], [25].

More importantly, spatial skills are not determined characteristics but flexible skills that can be cultivated through specific training and drilling. Various studies have shown that training in mental rotation before multimedia-based instruction in biology improves the performance of the students in the spatial domain and further learning [16], [24]. This observation implies that there is a two-way relationship between multimedia resources and instruction of biological information and context in which transferable spatial reasoning abilities develop. The malleability of spatial abilities creates some critical issues involving the sequence of the curriculum and the possibility of utilizing spatial abilities training into biology education.

4. Multimedia in Education

4.1 Evolution of Multimedia Technologies in Science Education

Multimedia technologies have been introduced into science education in a number of transformative stages in the last thirty years. The early multimedia applications in the 1990s were mainly computer-based animation and simulation that were used to supplement the conventional teaching. These tools were major improvements to the use of textbook illustrations that were limited on interactivity and two-dimensional displays. With the emergence of three-dimensional modelling software at the beginning of the 2000s, the qualitative change occurred as learners became able to manipulate the virtual object and observe the spatial relations in various perspectives.

The modern era of multimedia in the biology education can be described as the one of immersive and augmented reality technologies which erase the line between the physical and digital learning environment. The use of augmented reality applications can superimpose digital information to physical real-world environments and allow learners to see invisible biological structures imposed on their immediate surroundings. Virtual reality systems are complete digital environments that allow learners to move around cellular environments or interact with the molecular structures at scales that are unable to be achieved in the real world. These technologies are not only an incremental change but a radical transformation of the pedagogical affordances, which dislodge the traditional understanding of educational space and embodied learning.

Nonetheless, the level of technological sophistication does not necessarily lead into the level of pedagogical effectiveness. The most critical debates in educational technology research include the fact that multimedia tools should be based on instructional design principles and be aligned with certain learning goals. The educational technology history is full of instances of promising innovations that could not enhance the learning outcomes because of not integrating pedagogue, lack of teacher preparation or failure to meet the standards of a curriculum. More recent studies take into consideration the design-based methods of multimedia interventions testing and refining them in accordance with empirical findings about the nature of learning processes and results.

4.2 Types of Multimedia Resources in Biology

The current biological education practice makes a wide use of various multimedia technologies, each of which has its own set of affordances and constraints. Visualization software Visualization software, with 3-D capabilities, allows learners to view the anatomical structures, cellular structures, and molecular structures in different angles and zoom levels. The tools are especially helpful in teaching the subjects that need spatial comprehension, like the systems of the body, the structure of proteins and the interrelationship of ecosystems. It has been proven that three-dimensional programs are much better in strengthening the learning results than either plastics or two-dimensional systems, and learners display improved comprehension and interest [3], [16].

AR applications are a fast-expanding area of multimedia in the teaching of biology. These applications involve the use of mobile devices or tablets to superimpose digital 3D models on physical spaces to provide mixed-reality learning experiences. Augmented reality has been used in various biological areas such as cellular structure, human anatomy, ecology systems, and physiology processes. The technology

has distinctive benefits including portability, accessibility, as well as the possibility to combine digital content with tangible learning resources, including textbooks or lab samples [4], [6], [7], [9].

Virtual reality systems offer the most total multimedia experiences, as they transfer the learner to totally digital spaces where they can play with biological phenomena at scales and views they cannot see in the real world. Applications of virtual reality (VR) in biology learning include simulation of a laboratory environment, to an experience of learning about cellular events and an anatomy. Virtual reality escape rooms have been analyzed as gamified learning tools and 360-degree video game-based learning in the field of biology education [5], [8]. Although virtual reality has strong affordances of immersion, its implementation faces disadvantages such as cost and technical complexity as well as risk of cybersickness or cognitive overload.

5. Visual Thinking Skills

5.1 Conceptualization and Components

Skills of visual thinking represent the multifactorial group of cognitive skills which allow people to internally depict, operate and reason spatial information. In biology education, visual thinking is not only the ability to perceive images, but also to form mental representations of three-dimensional structures, be able to manipulate mental representations to take a new point of view, and combine spatial information with conceptual knowledge. These competencies are basic to the comprehension of biological phenomena in which space relationships, including molecular structures, cell organization, anatomical systems, and ecological patterns, are necessarily involved.

Modern cognitive science identifies a number of component skills in the larger construct of visual thinking. Spatial visualization is the capability to manipulate intricate spatial layout by applying numerous phases of transformation. Mental rotation is specifically ability to rotate two- or three-dimensional objects in the mind in order to identify their orientation or match them with target configurations. Spatial perception involves the process of establishing spatial relationships with reference to body orientation and spatial relation ability is the knowledge of how objects are arranged in space. These are the component abilities correlated with each other but differing in the pattern of development and in relation to academic success in biology.

Biological thinking in visual thinking has undergone changes towards conceptualization that includes domain-specific characteristics beyond the general spatial capabilities. Biological visual literacy involves the ability to comprehend representations using advanced representational icons like molecular

illustrations, phylogenetic networks and anatomical cross-sections. It further involves the capacity to give sizable representations a dynamic behavior by mentally animating them, as well as to synthesize information among many scales, including molecular to organismal to ecological scales. This domain perspective implies that good teaching in biology should be able to touch on general spatial skills and the representational practices that are specific to the discipline.

5.2 Mental Rotation and Spatial Visualization

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5.3 Individual Differences in Spatial Abilities

Personal disparities in spatial skills are also a crucial modifying variable when using multimedia resources to learn biology. Studies always show that spatial competencies have a significant range of variability among learners and such variation is predictive of the initial learning results and the extent of learning benefit as a result of multimedia intervention. High spatial ability students generally perform better when taught using three-dimensional representations and low spatial ability students can either suffer cognitive overload or not manifest the appropriate spatial information out of complicated representations [10], [17], [24].

Sex differences in spatial capabilities have been reported in the literature and in most instances, male gender exhibits superiority in the mental rotation exercises. Nevertheless, the extent and uniformity of these differences is different in studies and settings and modern studies have placed emphasis on experience, stereotype threat and instructional variables in developing perceived gender differences. Within the context of multimedia-based biology teaching, a number of studies have concluded that, when properly designed interventions are implemented, gender disparity in learning could be minimized or even eliminated, which implies that learning disparities in the initial stages (i.e. in spatial skills) could be compensated with the appropriate instructional support [16].

The identification of personal differences in spatial skills has significant consequences to instructional planning and delivery of multimedia tools. Scaffolding or other forms of representations to support learners with low spatial abilities might be required to accomplish fair learning results. Also, the plasticity of the spatial skills implies that explicit instruction in spatial skills can be used as an initial aspect of biology curricula, which may improve the ability of all students to take advantage of multimedia materials and to excel in spatially challenging subjects in biology.

6. Academic Achievement in Biology

6.1 Measuring Learning Outcomes

The learning in biology takes place in more than one form of learning such as the acquisition of facts, the acquisition of concepts, the acquisition of procedure and the application of knowledge to new issues. The learning outcome measurement in multimedia intervention research is usually based on the pre-test and post-test designs with the application of validated assessment methods that measure the level of content knowledge, spatial comprehension of biological structures, and the capacity to communicate about biological processes. The variety of methods used to assess studies are indicative of not only the

complexity of the knowledge in biology but also regarding the continuing controversy of what is the essence of meaningful learning in science education.

Standardized test scores, course grades, performance on researcher-created assessments and delayed interval retention measures are quantitative measures of academic achievement in research education studies on biology. Multimedia interventions have a significant range between small, medium and large effect sizes depending on the nature of the intervention, the quality of the implementation, the nature of learners and the sensitivity of the outcome measures. The meta-analytic methods have tried to combine these various findings to determine general effectiveness but the heterogeneity in study designs and outcome measures makes these syntheses difficult.

The modern methods of assessment are more and more focused not only on the factual knowledge but also on the deeper conceptual knowledge and the possibility to use the spatial reasoning methodology to the biological issues. Stimuli-Based Performance based tests, which involve mental manipulation of structures, or make predictions of functional implications of structural manipulations, or the combination of information among multiple representation forms are more realistic measurements of the visual thinking skills multimedia resources are intended to train. Nevertheless, their assessment methods are more resource-intensive to develop and to mark, and many studies turn to more conventional multiple-choice or short-answer methods that are not necessarily representative of the cognitive gains of multimedia interventions.

6.2 Challenges in Biology Education

There are a number of longstanding challenges in the field of biological education that can be mitigated by means of multimedia resources. To begin with, a great number of biological phenomena are observed at scales, or in conditions, which cannot be directly observed, necessitating their mental modelling by learners founded on indirect representations. The processes of cells, the interactions between molecules, and physiological processes are not perceivable, a major discrepancy exists between the daily experience of learners and the abstract knowledge they need to study. The use of conventional teaching methods that are based on two-dimensional theories and verbal explanations may not be enough to fill this gap especially to learners with little spatial skills or background knowledge.

Second, biology is a science about complex three-dimensional structures and how they relate to their functions, and advanced spatial reasoning skills, which have not been developed by many students. Anatomical education, especially, requires the capacity to mentally turn structures, combine data of

various cross-sectional perspectives and grasp spatial connections between organs and systems. It is repeatedly proven that students have difficulties with such spatial requirements, spatial skills predict achievement in anatomy and other courses in biology [14], [17], [25].

Third, the education in biology should accommodate significant individual variations in preexisting knowledge of the discipline, spatial skills and preferences of students with regard to learning. Conventional one-fit-all teaching methods are not always effective and efficient because different students perceive standard representations as being too simplistic and others are overloaded by cognition. Multimedia materials have the potential of differentiated instruction by providing adaptive interface, multiple representational format, learner-directed pacing and perspective, but the potential is only achievable with proper instructional design and execution.

7. Review of Related Studies

7.1 Three-Dimensional Visualization Technologies

Three-dimensional visualization software has been widely explored in the areas of improving spatial comprehension and academic performance in biology education. An early study by Jamil et al. investigated the usefulness of three-dimensional software in the instruction of anatomy to medical students of varying degrees of spatial intelligence [16]. The quasi-experimental study (n= 67) revealed that the students who were subjected to the mental rotation training before the three-dimensional instruction displayed high scores in rotation ($p = 0.011$) and low scores in time required to complete the task. Significantly, trained and untrained participants showed a considerable amount of learning through the use of the three-dimensional software ($p < 0.001$), and 97 percent of the students indicated that the technology was better than traditional plastic models. It has been determined that three-dimensional visualization is able to promote learning in students with diverse spatial capabilities, but in those with overall high capabilities, or specific training, its advantages were stronger.

Berney et al. examined the interaction between spatial abilities and dynamic visualizations in the learning of functional anatomy by using three-dimensional anatomy models [4]. Their study established that the usefulness of the three dimensional model is highly reliant on the spatial visualisation capacity of the learners and the level of interaction that is availed. The high spatial ability students were greatly benefited using interactive three-dimensional models and those with low ability needed more scaffolding to make good use of the technology. Implications of this aptitude-treatment interaction to differentiated

instruction are also significant and imply that uniform methods of implementing multimedia might actually widen achievement gaps, rather than narrow them.

In a study on spatial ability and learning in three-dimensional digital anatomy models, Labranche et al. studied the correlation with the students in their undergraduate level [17]. They revealed that spatial visualization skill was a predictive of learning in three-dimensional models with students in the highest quartile of spatial ability demonstrating much higher gains than the lowest quartile. Another finding of the study was that spatial abilities were improved through an extended exposure to three-dimensional models in addition to a semester, which implies that a bidirectional relationship exists between the multimedia resources and the spatial abilities as the former needs and builds spatial skills.

In the recent study conducted by Grannum et al. used a design-based research approach to design and assess digital three-dimensional aids in improving spatial thinking during anatomy studies [14]. Their repetitive practice underlined the usefulness of the pedagogical integration whereby it was found that three-dimensional tools best work when incorporated into the form of organized learning activities that clearly address the spatial reasoning abilities. The research has identified professional development of teachers as a means to facilitate successful introduction of three-dimensional visualization technologies.

7.2 Augmented Reality Applications

Among multimedia technologies, augmented reality has become one of the most actively studied fields in the field of biology education in the last ten years. Erbaş and Demir studied the impact of augmented reality on academic performance and motivation of students on a course in biology in a quasi-experimental study [9]. The researchers (n=52 seventh-grade students) have discovered that the augmented reality group significantly performed better than the control group on achievement tests ($p < 0.05$) and had a higher level of motivation. The AR application helped the students see the 3D models of cells, organs, and systems superimposed on their textbooks to offer them an integrated learning experience by bringing together both traditional and digital learning materials.

The study by Bogomolova et al. was a strict, double-centered randomized controlled trial study that studied the influence of stereoscopic augmented reality visualization on anatomy learning and the moderating role of visual-spatial skills [5]. The researchers (n=154 medical students) concluded that augmented reality was significantly more effective than traditional teaching and the effect sizes were variable depending on spatial capabilities of students at the beginning of the learning course. Critically, the experiment indicated that the inadequate spatial skills could be partially addressed by the use of

augmented reality, which indicates the possibility of lessening the gap in achievement. Nevertheless, even the highest spatial students demonstrated the largest absolute improvement, which proves the significance of the use of augmented reality in addition to the insignificance of spatial skills.

The article by Sattar et al. has compared Science AR, a curriculum-based augmented reality platform used to teach secondary biology subjects in Pakistan [30]. The quasi-experimental study (n=60, 9th-grade students) discovered that the augmented reality condition made the post-tests significantly better than in the control condition (81.0% vs. 76.1% p=0.022, Cohen d=0.61). The surveys of students showed the enjoyment, motivation, confidence, and clarity rated above 4.0 out of a 5-point scale. The educators claimed more attention, inquiring, and engagement during augmented reality lessons. The research revealed that augmented reality is applicable in situations with limited resources, and the issues of scalability and availability of advanced multimedia technologies are not a major concern.

Augmented reality implementation was found to have gender-based influences on the learning outcomes of biology, as studied by Tamam et al. [25]. Their research revealed that both male and female students were advantaged by augmented reality instruction although the effect sizes were different among gender and subject matter. This study demonstrates the relevance of going beyond the space skills and putting into consideration the individual differences to apply multimedia intervention and how augmented reality can be used to mediate gender disparities in science scores.

Dapitan et al. studied the application of augmented reality in biology education with the particular attention to the effect on the student academic performance [8]. In their study, they emphasized the role played by curriculum consistency and pedagogical consistency, as they discovered that augmented reality worked best when it helped to complement and complement traditional instruction. The implementation problems identified in the study were also technical issues, teacher preparation requirements, and the relevance of age-related content design.

7.3 Virtual Reality and Immersive Environments

Virtual reality is the most immersive mode of multimedia technology used in biology education, whereby completely digital environments are formed where students are able to interact with the biological phenomena on dimensions and angles never before achievable. Christopoulos et al. explored the concept of virtual reality escape room as a gamed-based way of teaching biology [7]. Their experiment investigated the potential of immersive virtual reality spaces to provide a greater level of interest and learning performance through the incorporation of biological information into stimulating game-based

experiences. Learners in virtual cells who solved puzzles by navigating through the virtual cells proved to be engaged and learned a huge amount of content, which implies that the immersive affordances of virtual reality can also be utilized to achieve motivation and cognitive advantages.

Froehlich et al. have performed a comparative experiment to determine the effects of immersive virtual reality on the learning of science not in the form of slideshow presentations [17]. Their study established that VR elicited much better learning and engagement than more traditional multimedia presentations with students saying that they had a greater sense of presence and that their spatial relationship comprehension was better. Nevertheless, the research also reported such challenges as cybersickness in certain participants and enormous time that was necessary to allow students to get accustomed to the virtual reality interfaces.

Zaatar investigated the effect of virtual reality on the undergraduate teaching of biological education at the American University in Dubai [28]. The participants of the study were the attitudes and learning results of students who studied various topics in biology using virtual reality, which showed positive outcomes, on average, on achievement and attitudes to biology. Nevertheless, the study also noted that the selection of content should be done carefully since virtual reality was found to be most helpful in instructing the subject that includes three-dimensional structures or processes that are hard to view directly and less helpful in instructing subjects that can be taught effectively using traditional instruction methods.

Vola et al. examined the effects of 360-degree video virtual reality on the performance and engagement of undergraduate students [27]. They concluded that student understanding of field-based concept of biology, and engagement was greater with 360-degree video presentation compared to traditional video presentation. The study showed that even the relatively uncomplicated virtual reality applications on the basis of 360-degree video can achieve valuable learning effects without the need of the technical sophistication and expense of full-fledged virtual worlds.

Zhao et al. conducted evidence synthesis by utilizing a recent network meta-analysis, which examined the use of immersive interaction and three-dimensional visualization technologies in anatomy curriculum [29]. The comparison was made on several types of technologies such as virtual reality, augmented reality, and three-dimensional models and the result was that all of them had positive impacts on the learning results in comparison to ordinary instruction. Nonetheless, the effect sizes were quite different among studies, and the biggest effects were obtained in those studies which also incorporated immersive technologies and included systematic instruction assistance and explicit training in spatial reasoning.

7.4 Comparative Effectiveness Across Technologies

The ability to compare various multimedia technologies has given valuable information on the relative efficacy and the proper use of the various methods. An important analysis of two-dimensional and three-dimensional representations in augmented reality established that the dimension played a major role in affecting the results of learning, albeit at a level checked by the spatial capacity of learners [2]. The three-dimensional augmented reality model created increased germane cognitive load and better spatial knowledge by high mental rotation ability learners and no benefit and at times made improvement with the simpler two-dimensional representations among low spatial ability learners. The observation contradicts the assumptions based on the fact that more sophisticated or realistic representations are generally better, emphasizing instead the need to tailor the complexity of the representation to the characteristics of the learner.

The comparison of the implementation of augmented reality and virtual reality has identified that both technologies deliver substantial learning benefits over standard instruction, albeit with varying affordances and constraints [13], [29]. Virtual reality offers more realistic experiences and better programmability of the learning environment with the benefit of being able to explore phenomena in extreme scales or dangerous situations, but with increased technical complexity and resource demands.

Research studies investigating effectiveness of multimedia intervention at various stages of education indicate developmental issues of significance. Studies on secondary students have mostly revealed positive impacts of multimedia technologies on achievement and engagement with augmented reality and three-dimensional visualizations demonstrating specific potential [9], [22]. Undergraduate and medical undergraduate studies have also reported such advantages, but with the added evidence that higher grade learners are capable of effectively interacting with more sophisticated and open-ended multimedia environments [16], [17], [28]. Such results imply that the multimedia interventions must be age-specific, and young students may require more structured and guided interventions, whereas more experienced learners can use more freedom and complexity.

7.5 Educational Stage and Context Effects

Multimedia resources have been shown to be effective in educational stages and settings, which are different in cognitive development of learners, their previous knowledge and their spatial skills. The studies conducted in secondary school students have repeatedly shown significant positive outcomes of multimedia interventions on academic performance and affective outcomes of motivation and

engagement. Research conducted by Erbaş and Demirer on seventh-grade learners revealed that augmented reality boosted not only outcomes but motivation in the science of biology [9]. Likewise, a study by Sattar et al. involving students at the 9th grade in Pakistan showed that augmented reality improved academic achievement, interest, and intentions to study biology [22]. These literatures indicate that multimedia technologies can be effectively used especially in the adolescent stage when students are acquiring abilities in abstract reasoning and when the tendency of students to learn science tends to reduce.

Undergraduate students have been studied to investigate the effectiveness of multimedia in more complex biology courses, especially anatomy and physiology. Studies on this regard have highlighted the significance of the spatial skills as predictors of learning of multimedia resources [17], [28]. Spatial competencies can vary more among undergraduate students when compared to young students, and the variability produces a large difference in benefits gained by using three-dimensional visualization and immersive technologies. It has been determined by studies that undergraduate courses leave the potential to do sustained exposure to multimedia in entire semesters, which allows exploration of longer-term effects on spatial skills and content knowledge.

Medical education is a rather concentrated area of multimedia application and most learning outcomes are of high stakes, and resources are quite substantial to integrate technology usage. Studies of medical trainees have reported that three-dimensional visualization and augmented reality have a large positive impact on the learning of anatomy and effect sizes are frequently large compared to other educational settings [5], [16]. But medical learning studies also emphasize the role of integration with clinical thought and the necessity of the multimedia resources to assist not only with spatial knowledge but with functional and clinical.

The multimedia effectiveness has been studied in various international settings through cross-cultural research and there are universal advantages as well as situational issues. Research carried out in contexts with limited resources has shown that even quite simple multimedia applications can result in significant learning outcomes, but technical infrastructure, training of teachers, and cultural suitability of material have an effect [22]. Comparative research has determined a generally consistent positive effect of multimedia, although with a range of variance in magnitude that has been linked to the characteristics of educational systems, the availability of technology and instructional traditions.

8. Conclusion

The systematic review of 30 studies proves that multimedia tools that include 3D visualization software, augmented reality (AR), and virtual reality (VR) have a significant effect on visual thinking abilities and academic performance in biology education. Evidential and quasi-experimental studies indicate moderate to high improvements in conceptual knowledge, test and spatial reasoning between the various levels of education and in various topics of biology.

Multimedia tools especially improve the ability of mental rotation and spatial visualization, which prove that the spatial skills can be developed with the help of specific training. Nonetheless, individual differences affect the level of effectiveness, namely, the initial spatial skills of learners, which leads to the necessity of adaptive and scaffolded teaching structures.

AR is convenient and simple, VR potential experiences are more genuine and provide more immersion, and 3D visualization software is highly territorial with medium complexity. They should also be selected in relation to the learning objectives and characteristics of learners and the availability of resources.

Another point that is highlighted in the review is that the effectiveness of multimedia is based on effective instructional design, with reference to the cognitive load theory and dual coding principles. Multimedia that is not designed well may augment cognitive overload.

The prospective studies in this field must address long-term retention, affective, various variables among learners, difficulties in implementation and combined pedagogy.

On balance, it is highly recommended to implement multimedia in teaching biology, but in a carefully planned way, with evidence-based practice and perception of the pedagogical objectives.

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