education sciences

Systematic Review

The Effect of Virtual Laboratories on Improving Students' SRL: An Umbrella Systematic Review

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Abstract: Virtual laboratory (VLab) has been observed for its function for the merit of online course delivery. It is believed that the existence of VLab may enhance students' academic achievements. However, the study which researches its impact on the students' independence is still limited. This systematic review study aims to determine students' self-regulated learning (SRL) on the use of VLab by implementing PICOS (Population, Intervention, Comparison, Outcome, Study Design). Further, we examined whether the strategies of SRL, such as cognitive, metacognitive, motivational, behavioral, and contextual strategies owned by students at higher education levels, increased because of leveraging the VLab. We identified 267 articles from Scopus and the Web of Science databases, then utilized the PRISMA guidelines to specify the 249 eligible articles. As a result, only 20 articles passed the criteria of the feasibility stage (1) higher education level, (2) informing online learning, (3) containing materials discussing VLab, and (4) representing the concept of SRL. However, the finding showed that all interventions had positively affected students' performance. Based on the analyzed data, we confirm that VLab can be considered for providing the learning experience since it bridges the gap between students' prior knowledge and experience and provides an active social experience.

Keywords: virtual laboratory; online learning; self-regulated learning; higher education

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1. Introduction

Some countries focus on STEAM (Science, Technology, Engineering, Art, Mathematics) education to create a generation that master's knowledge and skills in solving real-life problems [1–6]. Therefore, an agreement among educators with experiences in the laboratory is a crucial part of science education [7,8]. Furthermore, it is believed that laboratories are a place to increase students' knowledge about science and to practice their skills in conducting scientific experiments [9]. Thus, it is expected that the skills and experience that students gain in the laboratory can be applied to finding solutions to their real-life problems.

In this digital era, many educational institutions have been transforming their wet laboratories into laboratories that can be accessed remotely, known as remote labs [10]. In this mode, both lecturers and tutors carry out wet lab activities at school or campus while, supported by a set of computers and servers, students can access them from places outside of campus [11]. In subsequent developments, various potential technologies are used to support the operation of the laboratory, including the application of artificial intelligence and virtual/augmented reality [12]. Furthermore, virtual laboratories that utilize artificial intelligence technologies provide the experience of conducting scientific experiments through software that can classify the users' ability to use the applications [13].

Finally, virtual/augmented reality research shows how to conduct experiments in a virtual laboratory that closely resembles reality before they proceed to a wet laboratory [14], thus the laboratory's transformation to virtual mode is more favorable because it is perceived as more effective and efficient in conducting scientific experiments regardless of the course's quality and students' learning experience.

The benefits of virtual laboratories were increasingly required when the COVID-19 pandemic struck the world, and social distancing policies brought the impact of shifting face-to-face learning into online learning at all levels. Therefore, science learning practices are presented in virtual laboratories both in platforms and applications [15]. When the virtual lab is shown on the website (platform), students can run experiments without installing software packages on a mobile device. Instead, it is fully supported by servers [6] that can be accessed at home and at any time. The persistence of this policy's application urged teachers and students to be able to utilize the technology, as it is an obstacle for them in choosing a better strategy for solving a particular issue.

Previous research showed that the implementation of virtual labs in many levels of education made the learning process became more attractive, deepened students' understanding of the science material [16], and improved research assessments [17]. There is limited research related to the learning process through virtual labs that can contribute to the growing independence among students, how they struggle to understand online experiments without being guided directly by lecturers/tutors, and what strategies they apply to overcome the problems they face during the learning process. Therefore, this systematic review study aims to determine the self-regulated learning (SRL) of students on the use of the virtual lab by implementing the approach of PICOS (Population, Intervention, Comparison, Outcome, Study Design) (see Table 1). Through this literature investigation, the researcher needs to analyze whether the use of VLab can stimulate the independence and maturity of students in higher education in conducting experiments in every branch of science.

Table 1. PICOS Approach of the Study.

P	Population	Students in Higher Education Level
I	Intervention	Use of virtual and augmented reality technologies
C	Comparison	None
O	Outcome	Effect on Self-Regulated Learning
S	Study design	Systematic Reviews

According to Table 1, the author applied the general framework of the literature review in conducting the systematic reviews (S) based on the selected research focusing on students at higher education levels as the subjects (P). These articles also describe the function of virtual laboratory/augmented reality technology as the intervention (I) that impacts the SRL of students (O), without any comparison to other interventions (C).

1.1. Virtual Laboratory

Virtual Laboratories (VLab) are designed for several purposes, including preparing students to recognize the laboratory environment before engaging in real conditions. In addition, it is designed as the solution to overcome the problems faced when conducting chemical experiments in traditional classes. The intention to develop a VLab is reinforced by the descriptions of educators in various articles stating that its implementation is more economical, time-efficient, and able to reach more detailed experimental activities [14]. It can be inferred that the existence of VLab is a good prospect in creating the eco-pedagogy and accelerating the learning process while its appropriateness is still under review.

The introduction of basic concepts related to scientific experiments is the early history of the development of VLab. This initiative is motivated by the fact that VLab is the substitution learning technique that contributes to the achievement of several competencies in implementing scientific experiments [18]. Other competencies that are not fulfilled in VLab can be further implemented in the hands-on lab. These two techniques are confirmed by the developers of blended and hybrid labs. They introduce initial concepts and experimental techniques through VLab, then encourage students to carry out actual experiments in hands-on labs [19]. One of the competencies emphasized by blended and hybrid lab educators is social and communication skills that can be fulfilled when spaces are provided for exchanging ideas, discussions, and collaboration among students during experiments [20]. Based on VLab's progress, it can be explained that the industrial revolution era can transfer traditional learning into digitalized learning.

Advancements in ICT and digital platforms for VLab are not only superior for becoming learner-centered learning stimulants but being also able to support the realization of social interaction in the learning process. Previous studies had proven that VLab can produce better learning outcomes than experiments conducted directly in hands-on labs [21]. This is because VLab is equipped with simulation technology in 3D and virtual construction of animation, which is a combination of theory and practice that therefore encourages students to develop instruments tailored to their needs [16]. VLab is an innovative learning technique that is capable of involving students with abstract or unreachable scientific entities, phenomena, and concepts [22]. Through VLab, students would not be bothered anymore by learning the usage of equipment and materials of experiments, and they will have various activities in conducting the instrument efficiently in terms of time and cost.

The VLab system, which is the key to the virtual world, is presented in a platform or application. Students can carry out scientific experiments without the need to install software if VLab is presented in the form of a platform. They only need a computer/laptop/cell phone and the internet network to be able to access the VLab site address [23]. In some educational institutions, VLab in the form of a platform is developed independently, however, other institutions also provide VLab to students using available platforms, and either the students have to pay or the institutions give it to them for free. Each platform provides a variety of fields of study/courses, teaching media, discussion and evaluation rooms, and their respective facilities [15]. Other VLabs require users to download certain applications to be able to run experiments online [24], while the more advanced VLabs can present the virtual world via other platforms. However, some material and experimental activities in VLab require support from certain applications by other users. For those educational institutions which are aware of the importance of keeping up with the technology developments, VLab developments are supposed to be a great concern, whether it is platform or application. Besides gaining the benefit of VLab, it might be challenging the educational institution's attempts in providing the modification of learning style.

When we talk about platforms and applications, VLab was mostly developed to describe materials related to the branch of natural science, since the use of the word "laboratory" embedded in VLab is closely related to experiments in such branches of science. Nevertheless, nowadays many developers are starting to create VLabs for the branches of humanities and social science [25]. For example, in the field of historical studies, by using VR tools, students can be invited to penetrate the passage of time, for example they could go back to the days of ancient Egypt and Greece or during the years of World War II. In other fields of studies, such as sociology and anthropology, students are asked to travel around the world to get acquainted with various religions, cultures, and ways of life in other nations [26]. The more popular VLab is in the learning process, the more virtual rooms will appear for new courses and new fields of study. This will be beneficial for teachers to comprehend a concept from a different point of view.

1.2. Self-Regulated Learning

Students with strong self-regulated learning (SRL) will show their ability to plan, cope with, and evaluate the learning process that they use. They are usually able to create a conducive learning environment independently and have good academic achievements [27,28].

Some experts stated that SRL is a skill that can be sharpened and strengthened by the experience and by applying cognitive, motivational, behavioral, and contextual strategies in a metacognitive frame [29–31]. In other words, students with good grades and achievements academically or non-academically are the ones who evaluate themselves based on the SRL strategy.

If it is described one by one, a cognitive strategy is the ability of learners to adapt and change their intellectual processes to achieve their best academic performance [32]. This intellectual process is related to their ability to take control on how to learn, remember, and convey ideas reflexively and analytically. A motivation strategy is the personal goal of an individual who can move and strengthen to achieve the satisfactory academic performance [33,34]. Motivational strategies can block things that can discourage them from achieving their goals, including short, medium, and long-term goals as well as targets to be achieved in the future. This motivational strategy determines the understanding of their behaviors during the learning process [35]. Finally, behavioral strategies are when individuals can regulate themselves by observing and monitoring their attitudes and actions [30]. Two things represent behavioral strategies in SRL: First, students can manage time and place to be in harmony with their academic achievements [36]. Second, students will not hesitate to seek help from their colleagues if they face problems in the learning process. All these tips are done to achieve the expected academic performance. As a counter to these three strategies, metacognitive strategies will lead anyone to understand why, when, and how they use one or more of these strategies to implement the learning process [37,38]. This strategy is usually described as planning, self-monitoring, self-control, and evaluation. Moreover, the planning stage, self-monitoring, and evaluation will become a unit in metacognitive strategies that are always directed, lived, and revised during the learning process to achieve certain goals.

The strategies mentioned above do not only help students in the face-to-face or classroom learning process. Many studies have found that these strategies successfully make learners independent in online/MOOCs/distance/flipped learning [8]. For example, a survey by [39,40] stated that the SRL strategy could predict students' behaviors and goal achievements in MOOCs. Other studies described how SRL strategies could predict academic achievement by looking at learners' involvement in online learning [41]. Therefore, the students who master the SRL strategies in online learning will have more ability to control and manage themselves in the learning process. The right degree of this self-organized capability in the learning process will impact their academic transcripts.

2. Materials and Methods

In this segment, we depict the methodology of this systematic review (for an overview, see Figure 1) that adjusts to the PRISMA guidelines [42].

(1) Identification: The author collected and categorized journal articles starting in March 2021 through two indexed scientific literacy data centers, namely Scopus and Web of Science (WoS). The central theme of this study is observing online distance learning. Furthermore, as referred to in the research issues, the sub-theme will focus on the Virtual Lab topic as the sample. There are 267 (two hundred-sixty-seven) articles from the digital searching feature whenever we input keywords of the virtual lab (VL), virtual lab and remote learning, virtual lab and academic performance, virtual lab and self-regulated learning (SRL), virtual reality and SRL, SRL in online learning, and SRL in distance education. Those keywords have been described before relating to the impact of VLab on Students' SRL at higher education level. (2) Article Selection: In the article selection stage, the author reads the title and abstract of each article and conducted several further selections based on the following criteria: only available in forms of full papers, higher education levels, discussing virtual laboratories, describing self-regulated learning, containing online/distance learning, and deliberating academic performance. After that, 18 articles were excluded in the next stage because they were not available in the complete paper form. Therefore, for the next stage, the author only used 249 scientific articles. (3) Article Eligibility: In the article

feasibility stage, the author determines the return criteria, including its availability in English, reviews several articles related to the topic, examines how learning occurs at a higher education level, describes learning online or remotely through discussing virtual labs, and describes the concept of self-regulated learning or academic performance. (4) Included: In this "included" stage, the author divided articles into three main categories based on the chosen topic, in which they have 20 articles that explained the instructional design of online or distance learning. Moreover, those 20 articles discussed VLab and SRL strategies. The last category is articles about VLab in general, which crossed with the model of intervention, SRL as the predictor variable, social interaction, and reciprocation. (5) Extracted: The last part in the "Prisma Guideline" is to select articles based on the formulation of the research issue by looking at the overall description of the article starting from the title, abstract, introduction, literature review, methodology, findings, and discussions to the conclusions. In this stage, the author selects 20 articles categorized at the "included stage" to discuss the relationship between VLab and SRL strategies. The details are: (1) explaining the concept of VLab with the overall SRL strategy, (2) discussing virtual and augmented reality and the SRL strategy as a prediction of academic achievement, (3) describing the relationship between several SRL strategies in the use of VLab, and (4) how the success of students during the learning process in the virtual world is observed based on the strategies used.

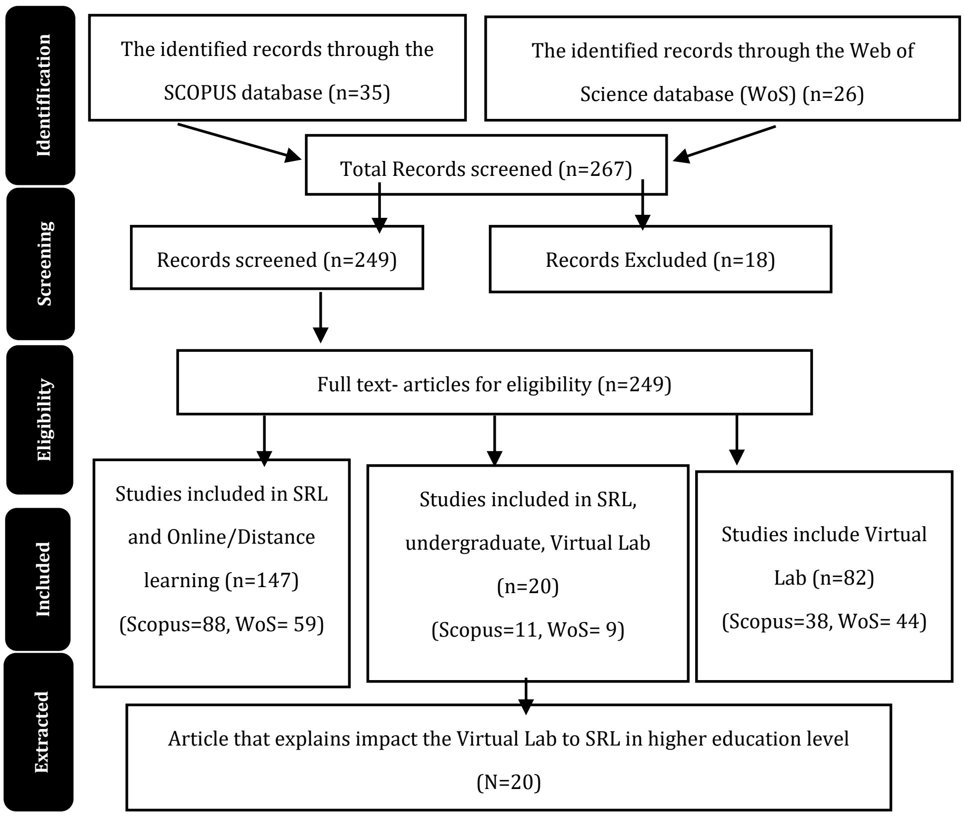

Figure 1. PRISMA Guidelines of the Study.

3. Results

In this section, the author presented a table that contains an overview of articles that have been reviewed. The author categorized those articles into the following categories: (1) intervention, explaining treatments or actions taken by the researchers in their studies by referring to the learning methods which are used, (2) variables analyzed in the studies, and (3) sources of relevant articles. More details are presented in Table 2 regarding the above description.

Table 2. Reviewed Article.

Intervention	Variable	Reviewed Article
Virtual Reality (VR) game-based English Mobile Learning Application	English Learning Effectiveness	[43]
Intelligent tutoring system, serious games, hypermedia, virtual learning environment	Multimodal SRL process data	[44]
Game-based learning for microbiology, crystal island	Level of students' agency	[45]
Educational Game (Physics Playground)	Self-Regulated Strategies	[13]
The use of Virtual Experiment Environments (VEEs) in natural science education	Students Engagement	[46]
Virtual Laboratories in Tertiary Education: Case Study Analysis by Learning Theories	Effective Learning Outcome	[47]
Strategy video games from cross-sectional (Social) studies	Individual differences	[48]
Virtual and remote laboratories augment self-learning and interactions: Development, deployment and assessments with direct and online feedback	Self-learning and interaction	[49]
3D Collaborative virtual learning environment (Eco-dialogical)	Sociocultural bounded places	[50]
The use of virtual lab (VL) and Microcomputer-based lab (MBL) in scientific modeling	Students' performance	[6]
The use of a virtual analytical chemistry laboratory (Pre-lab autonomous learning)	Students' achievement	[51]
The use of virtual learning applications in an educational institution (Online Virtual Laboratories)	Students' knowledge and practical skill	[52]
The use of virtual reality for a biomedical science course	Learning outcomes	[53]
Systematical Review of Virtual environment	Self-regulated learning	[54]
[[[The impact of simulation laboratory on continuing engineering students	Students' academic performance	[55]
Self-regulated learning: the effect on medical student learning outcomes in a flipped classroom environment	Flipped Classroom & SRL	[56]
Comparison of In-Person and Virtual Labs/Tutorials for Engineering Students Using Blended Learning Principles	VLab, learning outcome	[57]
How do students' self-regulation skills affect learning satisfaction and continuous intention within desktop-based virtual reality? A structural equation modeling approach	SRL, Virtual Reality	[58]
Epistemology, socialization, help seeking, and gender-based views in in-person and online, hands-on undergraduate physics laboratories	Virtual Lab, help seeking	[59]
Examining sequential patterns of self- and socially shared regulation of STEM learning in a CSCL environment	computer-supported collaborative learning (CSCL) environment, STEM	[42]

4. Discussion

This paper presents an overarching review of related literature to determine students' self-regulated learning (SRL) experiences while utilizing a VLab. The primary constraints of the study are the authors' inability to find more relevant articles on the topic that meet the eligibility criteria. Findings revealed that most of the prevailing research is concerned mainly with the organization of virtual labs in the learning process at the higher education level remotely, together with the impact of self-regulated learning or academic performance on actual learning outcomes. Seven key observations are shared in the following paragraphs, and they are: (1) this virtual learning experience yields positive outcomes at various stages of the teaching and learning process; (2) the VLab encouraged students to think creatively; (3) the use of the VLab enhances students' autonomy in learning; (4) VLab aided in teaching conceptual knowledge through visual effects and made it simple to apply the knowledge in various simulation models; (5) VLab can improve learning outcomes; (6) the VLab allows students to develop their leadership abilities; (7) VLab can improve students' research and analytical skills. These observations marked current trends in the creation and deployment of virtual learning environments. At the same time, they predicted changes that will happen shortly concerning these virtual teaching and learning initiatives.

First and foremost, this virtual learning experience yields positive outcomes at various stages of the teaching and learning process. A VLab can be considered a model for providing the learning experience through stages that must be completed, namely real experience, reflective observation, abstract conceptualization, and active experiments [43,58]. Furthermore, it bridges the gap between students' prior knowledge and lived experiences [44,45] while providing a dynamic social experience [50]. Thus, it can be argued that using VLab contributed to developing students' knowledge, skills, attitudes, and habits of mind, all of which they carry with them after completing a learning experience. This is in line with research conducted by [19] at one of the middle schools in Saudi Arabia; it is known that after carrying out the actual experiments in the VSL, it was discovered that 80% of students had a decent comprehension of them. In this context, individualized learning is achieved through group activities, demonstrating the close relationship between cognitive theory and social constructivist theory. Indeed, this teaching and learning initiative also considers the heterogeneity of users and the fact that individual learning experiences are significant in SRL.

Second, the VLab encouraged students to think creatively because it gives them the resources to create their educational environments rather than having their learning environment entirely controlled by their tutor or isolated [47,49,60]. This is an indirect contrast to the learning-by-rote tradition that puts the teacher at the center of the stage. The 3D collaborative Virtual Learning Environment (VLE) supports realistic and immersive experiences which stimulate self-regulated learning and requires the students to explore the learning by themselves and collaborate with their peers. Consequently, students create knowledge through experience, which also transforms them as individuals, and the educator's role is changed from that of an instructor into that of a facilitator. The application of VLab also has implications for students' cognitive and behavioral engagement [47,49,58]. It is possible to delineate cognitive engagement as students' interaction with educational activities and their constant search for solutions to given problems. Moreover, behavioral engagement can be identified as students actively participating in VLab activities, including their efforts to complete academic tasks, because they have faith in their abilities.

Third, it is found that the use of the VLab enhances students' autonomy in learning. This is an intriguing aspect, and students rated this fact highly positively. The ability to personalize learning and call on students' metacognitive knowledge is also facilitated [44,45,47,60]. VLab provides a variety of scaffolding activities to help students develop their metacognitive self-regulation skills. Through the interaction between students and VLab resources, students can regulate their learning processes in virtual learning environments (VLabs). Perhaps the experience of being immersed in learning is one that is both meaningful and 'real', and these factors strongly contributed to the success of this teaching and learning initiative. Indeed, compared to the traditional classroom setting that is highly contrived and intensely regimented, we can see the strength of VLabs as a productive educational initiative, especially for younger students who have been exposed to teaching and learning technologies at a young age. These students not only enjoyed being in virtual environments but also revealed the opportunity to experience learning within technologically mediated spaces.

Fourth, VLab aided in teaching conceptual knowledge through visual effects and made it simple to apply the knowledge in various simulation models. It significantly motivates and improves students' conceptual understanding of the subject matter being taught [49,57,61]. Furthermore, it can be used anywhere when the area has an internet connection, with flexible time slots, the ability to simulate hazardous scenarios, and at a low cost [62]. It aids in developing students' confidence in applying learned concepts in real-world situations [50]. It has a positive impact on students' learning levels and aids in achieving learning outcomes and, ultimately, the achievement of program objectives effectively [55]. As previously stated, the learning investment of students, which includes their willingness to exert the efforts necessary to comprehend conceptual knowledge, helps to promote cognitive engagement in students.

Fifth, in presenting an active learning experience, VLab can improve learning outcomes through an interactive experience that immerses the users in a digital environment through a sense of presence [53,56,57]. It has been shown in past research that [22] students may study abstract and inaccessible entities with VLab. Exposure and immersion are critical experiences observed in the successful deployment of virtual learning environments in different educational stages, from preschool to college or university. In addition, VLab climates necessitate self-regulation as students become active agents throughout the teaching–learning process. At the same time, self-regulation in technology-enhanced learning environments presents numerous challenges, particularly in students' commitment, motivation, social connection, and feedback [54]. Therefore, the VLab must be designed with specific learning outcomes in mind and scaffolded appropriately to support students' learning experiences. As aforementioned, the VLab initiative can improve the learning experiences of students. That being said, this virtual learning initiative must be carefully and thoughtfully designed to provide students with an authentic, engaging learning experience that will motivate them to continue learning and enjoying the subject matters they are pursuing at college or university levels.

Next, the VLab allows students to develop their leadership abilities. Despite being ephemeral and project-oriented, it creates opportunities for members with the necessary skill sets within the self-regulated community of learning (SRCL) [42,56,59,63]. Students learn to manage their project and their members, which will improve their leadership and organization skills. The leaders of an SRCL ensure that the organization's success in achieving both individual and communal benefits is enhanced while also enhancing the organization's egalitarian nature. In addition, representing a significant pedagogical shift from the ground up of instructional approach, it strongly emphasizes student-led learning. In addition, students demonstrate a positive attitude and a willingness to experiment with new technologies in the VLab, which is reassuring, at the very least. They reported that they understood the subject matter better, increased confidence, and had a greater interest in the lab experience. Furthermore, students asserted that it is easier to understand factual data because the VLab system is simple to use, and it collects data with high accuracy [6]. This is perhaps due to the 'UX' and 'UI' components of virtual labs; UX refers to user experience design, while UI stands for user interface design. VLabs that consider the user interface can enhance user experience and vice versa. Whether for learning about leadership or for acquiring facts and figures, virtual learning environments with state-of-the-art user interfaces can and will lead to the best user experience. Since information and computer technologies have become more complex and widespread, we can only expect educational experiences through virtual learning environments to become more productive as a medium for teaching and learning. This is because there are still limits to the deployment of virtual learning environments, for example, those created by current hardware and software applications that are limited by current technological bottlenecks.

Finally, using VLab can improve students' research and analytical skills due to the meaningful learning process that takes place within the virtual learning environment [42]. This statement is in line with the study conducted by [16] on pre-service teachers in a virtual biology laboratory. The evaluation conducted by the researchers found that 80% obtained scores above the average related to cognitive, affective, practical skills, and technology levels. Additionally, the VLab may serve as a visual aid to teach complex concepts that involve the students thinking critically and analytically. The instructors also can capture students' attention by allowing the students to use and test all the equipment online and offer instant feedback to students. It is not strange to find that the willingness of students to participate in basic research projects that require the application of analytical knowledge to advance the field may be greater than their willingness to participate in advanced research projects. The VLab initiative can become a game changer in this respect when we consider the possibility that students will be able to use virtual workspaces to their advantage by lessening their fear of limitless knowledge and highly technical information or advanced communication technologies. By spending much time being exposed to virtual learning environments and immersed in the ability they must acquire within those environments, these students should be able to improve their research and analytical skills as a result of their virtual learning experiences. In addition, students may be better prepared to adapt to the demands they frequently encounter when developing working strategies involving virtual resources due to this form of virtual learning [64]. Thanks to the use of VLab, students can interact with authentic materials, which may then aid in the development of scientific literacy amongst them. The experience may also help to develop a fundamental understanding of unintelligible phenomena by providing hands-on experiences [51].

Of the many advantages of VLab in scientific experiments, it is difficult to find a weakness in VLab. This is because every educational and non-educational institution that develops VLab constantly improves and adds to its functionality. When some educators and students question complex experiments in hands-on labs that the VLab cannot replace, studies show elaborate simulation models of advanced scientific experiments that can answer these problems [65]. However, there are several weaknesses associated with the use of Virtual Laboratories. The emergence of VLab also raises doubts about the need for more social interaction among students while using VLab for the learning process. Several studies have also found this problem by adding more group activities that require collaboration among students in experimental tasks on the VLab platform and application. One of the disadvantages of VLab is that it diminishes direct communication among students, instructors, or teachers in the laboratory. Moreover, it can reduce safety awareness and increase risks connected with laboratory work [66].

Furthermore, the high cost and lack of qualified human resources in the development and expansion of VLab infrastructure at institutions with VLab have often been obstacles from the start [42,67]. However, as time goes by, IT companies develop and offer VLab platforms with various needs. Thus, educational and non-educational institutions can take advantage of VLab without having to establish the same themselves. The VLab demands a professional team of experts, for example, in programming languages, scientific material, teachers, and psychology. According to the study showed that virtual lab experiments need professional assistance or professional programmers with strong administrative efforts [68]. Moreover, the students require computer tools with high specifications to accelerate the accurate phenomena with full features. Believed that the virtual lab requires technical assistance and a committed system fully maintained by the Information and Technology Department [69]. Therefore, the VLab application not only highlights its strengths but also has some drawbacks for students. Based on this discussion, we can understand that the real problem of the existence of VLab is how developers or institutions always respond quickly to VLab's weaknesses and shortcomings with innovation through research and development.

5. Conclusions

This research lays the groundwork for advancing technology in leveraging the quality of the learning process to advance educational theory and practice. Until recently, most academic researchers investigated the digital learning environment, including transitioning from traditional to online learning. The approach of PICOS is used to conduct a systematic umbrella review of students' self-regulated learning (SRL) when using a virtual laboratory (VLab).

The authors' inability to locate additional identified articles relevant to the topic and the eligibility criteria for the articles are the most significant constraints on the review. Furthermore, finding effective ways to link empirical work back to theory to contribute to generalizable knowledge is a considerable challenge in this domain. The findings revealed that most of the current research is concerned with the organization of virtual labs in the learning process at the higher education level remotely, as well as the impact of self-regulated learning or academic performance on learning outcomes at the higher education level remotely. The current study, which uses VLab, provides a window into the reality of SRL over time for the general benefit of online learners. In this type of research, skills and experience gained by students in the VLab are documented. Additionally, it demonstrates how students construct knowledge in the VLab through engagement and active learning. They take appropriate activities, ideas, feelings, and behaviors in pursuit of worthwhile academic goals, self-monitoring and self-reflecting on their progress towards learning goal completion. The research findings support applications in the novel context with various affordances and are concerned with broader implications. Many assessment instruments have been developed in the hands-on lab for students conducting scientific experiments. However, this instrument is to measure students' skills at cognitive, affective, and also psychomotor levels. This reason is the reference for further research, namely the need to develop instruments for scientific experiments that use virtual laboratories. This aims to assess the knowledge and skills acquired by students and further influence their learning outcomes.

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